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This study is an evaluation of the Korean harbors of Inchon, Pusan, and Chinhae as typhoon "havens." Characteristics of the harbors discussed include wind and wave action, storm surge and the topographical effects on winds prior to and during the passage of tropical cyclones. Problems to be considered when remaining in port, and possible evasion

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procedures are examined.

The tracks of tropical cyclones from 1947-1973 for the western North Pacific were analyzed to determine the probability of threat to the harbors. Observations by the author and information obtained in conversations with harbor authorities are utilized in reaching conclusions.

The conclusion reached by this study is that only ships berthed in the Inchon tidal basin are safe from typhoons; that all vessels should evade from Pusan when threatened by a typhoon and that Chinhae harbor is a safe haven for ships of destroyer size or smaller, and that larger ships can safely anchor in Chinhae Bay during a typhoon.

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# AN EVALUATION OF THE HARBORS OF INCHON, PUSAN, AND CHINHAE, REPUBLIC OF KOREA AS TYPHOON HAVENS

by

DIETER K. RUDOLPH

DECEMBER 1975

NAVAL ENVIRONMENTAL PREDICTION RESEARCH FACILITY
MONTEREY, CALIFORNIA 93940

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## FOREWORD

COMSEVENTHFLT has requested that twenty-two western North Pacific and Indian Ocean ports be evaluated as typhoon havens. CNO tasked COMNAVWEASERV with the preparation of these evaluations, and in response to a request from COMNAVWEASERV, COMNAVAIRSYSCOM tasked NAVENVPREDRSCHFAC with the development of these studies.

The present study of the Korean harbors of Inchon, Pusan and Chinhae represents another step in the overall task, the final goal of which is a comprehensive typhoon havens handbook containing condensed studies for the twenty-two designated ports in the western Pacific/Indian Ocean. This particular analysis was prepared by LT D. K. Rudolph, USN, at the Naval Environmental Prediction Research Facility.

The assistance of the Naval Weather Service Detachment, Asheville; Commander Naval Forces, Korea; Naval Advisory Group, Chinhae; Military Sealift Command, Pusan, and the Republic of Korea Naval Hydrographic and Meteorology Sections, Seoul and Chinhae, in providing data, reports and comments is gratefully acknowledged.

R.C. SHERAR
Captain, U.S. Navy
Commanding Officer
Naval Environmental Prediction
Research Facility

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# 1. INTRODUCTION

One of the most destructive weather phenomena a ship may encounter, whether it be in port or at sea, is the tropical cyclone and, in particular, the typhoon. The commanding officer, when faced with an approaching severe tropical cyclone or typhoon, must make the following timely decision: should the ship remain in port, evade at sea, or, if at sea, should the ship seek shelter in a harbor?

For most western North Pacific harbors there is insufficient or inadequately documented evidence as to the degree of shelter which the port affords ships from typhoons. Furthermore, the uncertainty associated with an anticipated typhoon track and intensity makes it difficult to provide reliable estimates of wind and sea conditions to be expected well in advance of a typhoon's passage. Consequently, the prudent mariner has found it advisable to commence evasive action upon the first indication that a typhoon may strike the port in which his ship is berthed. Considering the majority of harbors, this is undoubtedly true. However, it is becoming clear that there are certain harbors where some ships would be safer in port than at sea. Previous studies indicate that the harbors of Hong Kong (Mautner and Brand, 1973), Kaohsiung and Chilung (Keelung), Taiwan (Brown, 1974), and Manila, Republic of the Philippines (Douglass, 1975) are definitely not typhoon havens. If ample warning time is given, evasion from Subic Bay, Republic of the Philippines, is also recommended (Douglass, 1975). The Japanese harbors of Yokosuka (Graff, 1975) and Sasebo (Rudolph, 1975) are typhoon havens. In the case of Sasebo, evasion is recommended for aircraft carriers if 72 hours are allowed for sortie. This study evaluates the Korean harbors of Inchon, Pusan, and Chinhae as typhoon havens.

# 2. TROPICAL CYCLONES

## 2.1 DEFINITION AND DEVELOPMENT

A tropical cyclone is a low pressure disturbance whose central core is considerably warmer than the surrounding air. It differs from mid-latitude (extratropical) cold-core cyclones in its origin, dynamics, and the meteorological characteristics of the air masses involved. Like typical low pressure systems, the wind circulation in a tropical cyclone is counterclockwise about its center in the Northern Hemisphere and clockwise in the Southern Hemisphere.

The primary region of tropical cyclone development lies between latitudes 25N and 25S, except very near the equator. The area between the latitudes 5N to 20N and from 170E longitude to the Philippine Islands produces more tropical cyclones than any other region in the world. It is in this area that the water temperature is always above 26°C (78.8°F). Empirical data indicates that warm water such as this is a necessary condition for the development and intensification of tropical cyclones. These warm ocean waters over which the tropical cyclones travel provide the energy required for the growth and sustenance of the storm (Palmen and Newton, 1969).

## 2.2 CLASSIFICATION

The following classification system concerning the intensity of tropical cyclones has been established by international agreement:

Tropical Depression: Maximum sustained winds do not exceed 33 knots.[1]

---

[1]Sustained wind is defined as the average wind over a specified time period.

Official consecutively numbered warnings are disseminated by the Fleet Weather Central/Joint Typhoon Warning Center, Guam (FWC/JTWC) on tropical depressions which are forecast to become tropical storms within 48 hours. In WESTPAC, FWC/JTWC issues these and other tropical cyclone warnings at six-hourly intervals.

| | |
|---|---|
| Tropical Storm: | Maximum sustained winds between 34 and 63 knots. |

Most of the tropical depressions will intensify into tropical storms. Tropical storms are named in alphabetical order from four consecutive lists of women's names.

| | |
|---|---|
| Typhoon: | Maximum sustained winds in excess of 63 knots. |

About two-thirds of the tropical storms intensify to typhoon force. At this stage, the well-known "eye" with relatively calm winds and clear skies will develop at the center. The "eye" is surrounded by a wall of clouds where the strongest winds and heaviest rain are found.

## 2.3 MOVEMENT

The majority of tropical cyclone tracks conform to a general pattern by initially moving west-northwest from the source region. Steered by the prevailing easterlies, the tropical cyclone moves at speeds from 8 to 14 kt. Normally, upon reaching latitudes between 20-30 N, tropical cyclones are influenced by the prevailing westerlies and undergo "recurvature." This implies that the west-northwest movement gradually shifts to a northeasterly direction. After recurvature, the tropical cyclone's speed of movement can accelerate within 48 hours to as much as 2 to 3 times the speed at the point of recurvature (Burroughs and Brand, 1972).

However, in conjunction with the increase in speed of movement, a gradual weakening occurs as the tropical cyclone moves over cooler waters or when cool surface air enters the storm system.

It is important to keep in mind that the course of individual storms cannot be said to follow any standardized pattern. Numerous typhoons have followed extremely erratic courses, even making occasional loops in their tracks. For this reason, the progress of each typhoon should be closely monitored for changes in intensity, direction and speed of movement. The western North Pacific average typhoon tracks, track limits and average speed of movements for the months of June-October are presented as Appendix A.

## 2.4 WIND CIRCULATION AND INTENSITY

The counterclockwise wind circulation about the eye of a typhoon in the Northern Hemisphere is depicted in Figure 1. Note that in the upper portion of Figure 1, the wind circulation and typhoon speed of movement are in essentially the same direction. This results in winds of great intensity and a high sea state. Ships located in the forward right quadrant tend to be pushed into the path or center of the typhoon as a result of the circulation pattern. For these reasons, this area is known as the "dangerous" semicircle.

In the lower quadrants, the typhoon direction of movement and wind circulation are opposed. This results in a somewhat calmer sea state and less intense relative winds than in the "dangerous" semicircle. Ships in the lower rear quadrant will be pushed into the wake of the typhoon by the circulation pattern. The lower two quadrants comprise the "navigable" semicircle. The terms "navigable" and "dangerous" are used in a relative sense. The winds and seas are dangerous anywhere near the center of a typhoon.

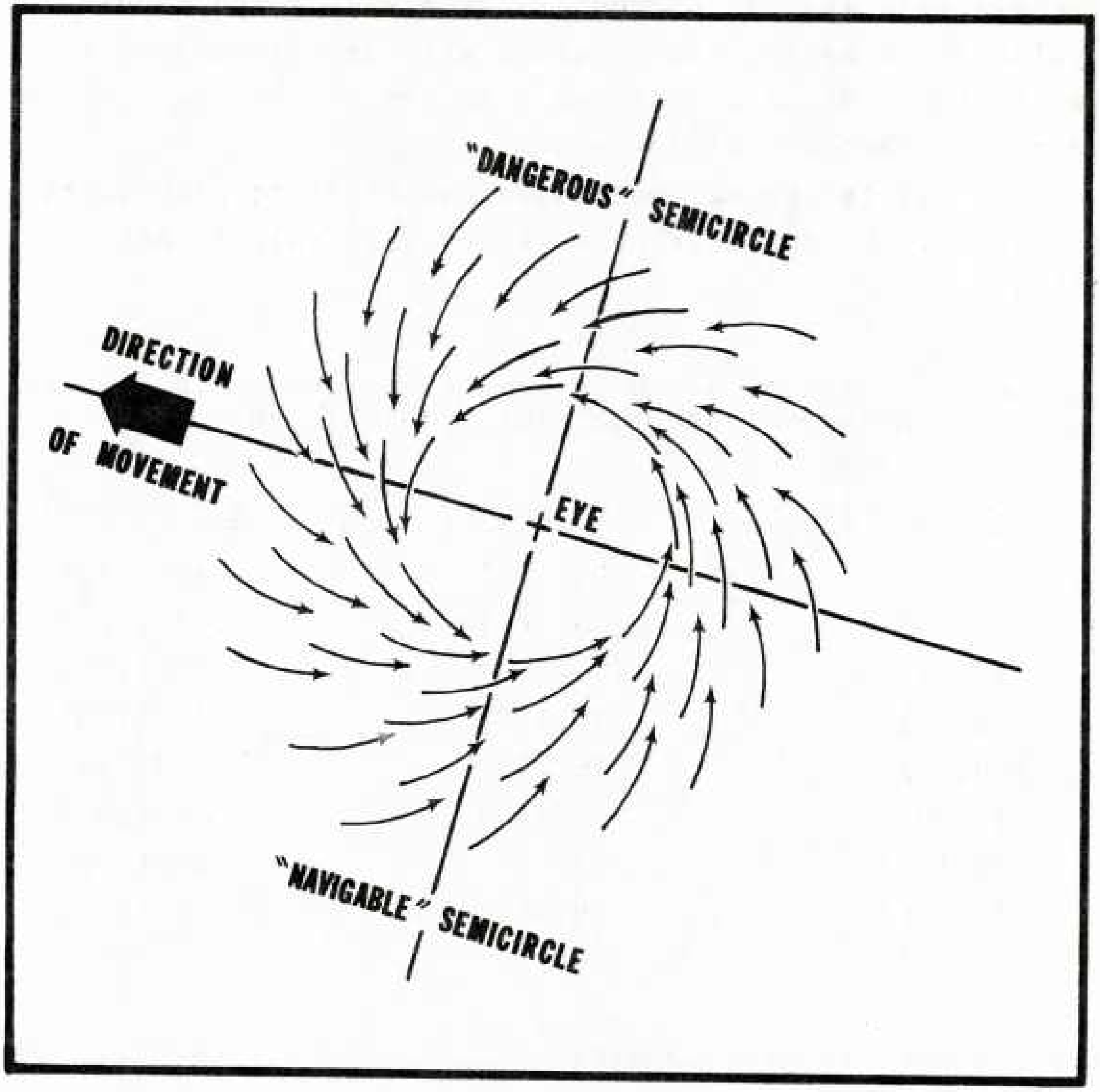


Figure 1. Wind circulation of a tropical cyclone in the Northern Hemisphere indicating the "dangerous" and "navigable" semicircle (after CINCPACFLT OPORD 201-YR, Annex H).

The maximum winds usually occur near the center and near the eye wall (clouds surrounding the eye of the tropical cyclone). However, strong winds will usually extend a considerable distance outward from the center, particularly in the dangerous semicircle.

To relate the maximum sustained winds to peak gusts in a tropical cyclone over open water, see Table 1 (Atkinson, 1974).

Table 1. Relationship between sustained 1-minute wind (kt) and peak gust (kt) for tropical cyclones.

| WIND (GUST) | WIND (GUST) | WIND (GUST) |
|---|---|---|
| 50(65) | 95(115) | 140(170) |
| 55(70) | 100(125) | 145(175) |
| 60(75) | 105(130) | 150(180) |
| 65(80) | 110(135) | 155(190) |
| 70(85) | 115(140) | 160(195) |
| 75(90) | 120(145) | 165(200) |
| 80(100) | 125(150) | 170(205) |
| 85(105) | 130(160) | 175(210) |
| 90(110) | 135(165) | 180(220) |

For example, if maximum winds of 140 kt are forecast, then gusts of 170 kt can be expected.

## 2.5 SEA STATE

Wave development is a function of wind intensity (the stronger the wind, the more rapid the development and the greater is the maximum height of fully developed waves), wind duration, and the distance (fetch) over which the wind is acting.

Since the strongest winds are found near or just outside the eye, it is here that the seas develop most rapidly. The swells traveling out ahead of the storm originate in the "dangerous" semicircle while those traveling toward the rear originate in the "navigable" semicircle.

The waves generated near the center usually travel faster than the storm and are often observed well ahead of the typhoon as long, low swells. For this reason, they are commonly referred to as "forerunners." It is important to realize that sea conditions affecting ship movement will extend well beyond the wind field associated with a tropical cyclone. A miscalculation concerning sea conditions could result in a destructive rendezvous with the storm.

Figure 2 shows the combined sea height[2] associated with 21 tropical storms and typhoons (based on 173 analyses for the year 1971) plotted as a function of distance from the storm center and storm intensity (Brand, et al., 1973). There is an obvious relationship between the sea state and storm intensity. A tropical storm (wind category 34-63 kt) can produce 12-ft seas 210 n mi from the storm center, while an intense typhoon (wind category $\geq$ 100 kt) can produce 12-ft seas 454 n mi from the center. The distances given are mean distances since the isopleths of combined sea height are not symmetric about the storm center. Brand, et al. (1973) found

---

[2]The combined sea height is defined as the square root of the sum of the squares of "significant" sea and swell height. Sea is wind waves, and swell consists of wind-generated waves which have advanced into regions of weaker or calm winds. "Significant" will be defined here as the average height of the highest one-third of the waves observed over a specified time.

that the actual wave heights are at least partially dependent on the direction in which the storm is moving. For example, Figure 3 shows the average combined sea-height pattern for recurved storms moving on headings between 001° and 090°, and is based on 24 sea-state analyses for tropical storms and typhoons that occurred during 1971. Note that the greatest area of higher seas (9-15 ft range) exists in the right (dangerous) semicircle of the storm.

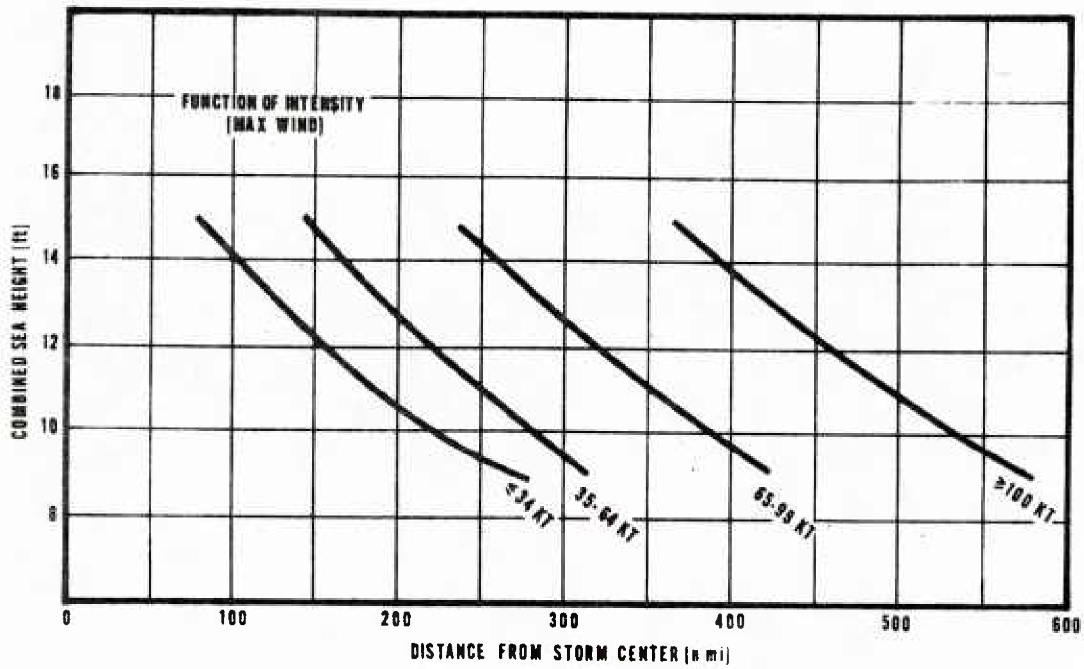


Figure 2. Combined sea height plotted against distance from storm center and given as a function of storm intensity (Brand, et al., 1973).

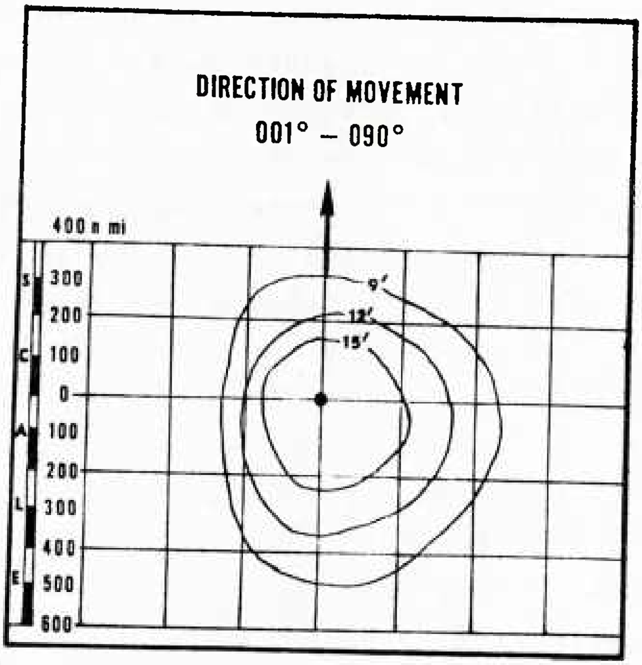


Figure 3. Combined sea-height isopleths (9-15 ft) based on 24 analyses of tropical storms and typhoons heading between 001°-090°. The mean speed of movement and mean wind speeds for these 24 analyses were 12.1 and 64.6 kt, respectively (after Brand, et al., 1973).

## 3. KOREA

Figure 4 shows the geographical location and topography of the Korean Peninsula in the western North Pacific Ocean. To the north, Korea is bounded by Manchuria, and to the extreme northeast by Soviet Siberia. Since almost one-third of the tropical cyclones affecting Inchon travel across the eastern coastal areas of China, and over 40% of the tropical cyclones affecting Pusan/Chinhae traverse southwestern Japan, the topography of the respective regions has also been included in Figure 4.

Since 1945 the Korean Peninsula has been occupied by two states, the Republic of Korea (R.O.K.) in the south and the Democratic People's Republic of Korea in the north. They are separated by a demilitarized zone along the armistice line of 1954.

Mountains ranging between 3000-6000 ft are found in the central and eastern portions of the Peninsula's tip. Along the eastern shore of the Korean Peninsula a 3000-6000 ft range extends north to the Manchurian border where two mountain ranges extend up to 9000 ft.

A detailed study of the coast and harbors of Korea is included in H.O. Pub. 157, Sailing Directions (Enroute) for the Coasts of Korea and China.

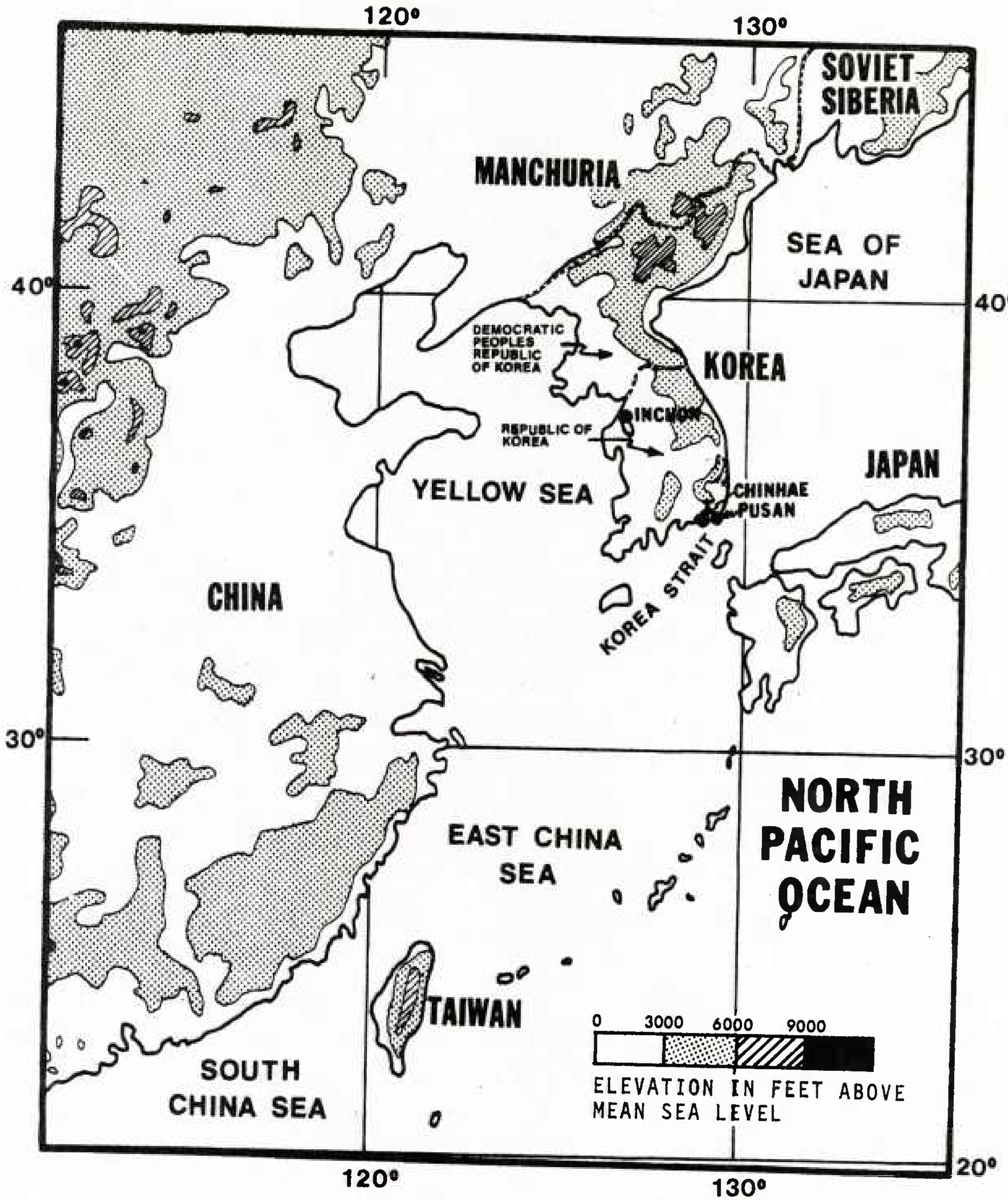


Figure 4. Map of the western North Pacific Ocean showing the positions of major land masses and topography.

# 4. INCHON

## 4.1 LOCATION

Figure 5 shows the location of the port of Inchon at 37°28'N, 126°37'E on the west coast of the Korean Peninsula. Approximately 16 n mi to the northeast is Seoul, the South Korean capital. The port of Inchon serves as commercial outlet and port of entry for Seoul and is one of the largest cities in Korea. Inchon is situated on the estuary of the Yom River, a subsidiary outlet of the 320 n mi long Han River, which flows past Seoul.

## 4.2 INCHON HARBOR

Inchon Harbor, one of Korea's principal deep water ports, consists of an outer harbor, an inner harbor for coastal vessels, and a tidal basin used by ocean-going vessels (see Figure 6).

The outer harbor consists of the Yom River area which provides numerous anchorages for deep draft vessels (see Figure 5). U.S. Navy ships are generally assigned anchorage E-3 or E-4. The holding action of the outer harbor bottom is best in the B anchorages while the A anchorages in the northern part of the harbor offers poor holding action in a rocky bottom. The large tidal range of 30 ft in conjunction with the strong currents which can exceed 3 kt make anchoring in the outer harbor inadvisable during a typhoon.

The inner harbor is used only by coastal vessels and is located south of So Wolmi Do (see Figure 6).

The tidal basin is entered through either of two adjoining locks located between Wolmi Do and So Wolmi Do (see Figure 6). The currents in the vicinity of the lock gate run perpendicular to the lock entrance and, therefore, the tidal basin is entered only during slack tide. It takes

approximately 1-1½ hours to clear the lock. Depths within the main part of the tidal basin varies between 4-5 fathoms; however, there are certain areas where the water is considerably shallower.

Inchon Port is controlled and managed by the office of the Marine Bureau, Ministry of Transportation, ROK.

## 4.3 TOPOGRAPHY

Figure 5 indicates that Inchon Harbor is well protected by hills generally over 300-400 ft in all directions except to the southwest. The tidal basin receives further protection from the northwest by Wolmi Do with a height of 104 ft (see Figure 6).

## 4.4 HARBOR FACILITIES

For a detailed description of harbor facilities available in Inchon, the reader is referred to CINCPACFLT Port Directory, Volume V, section B3 or the Far East Port Directory, MSCFE INSTRUCTION 3170.4A, section II-4.

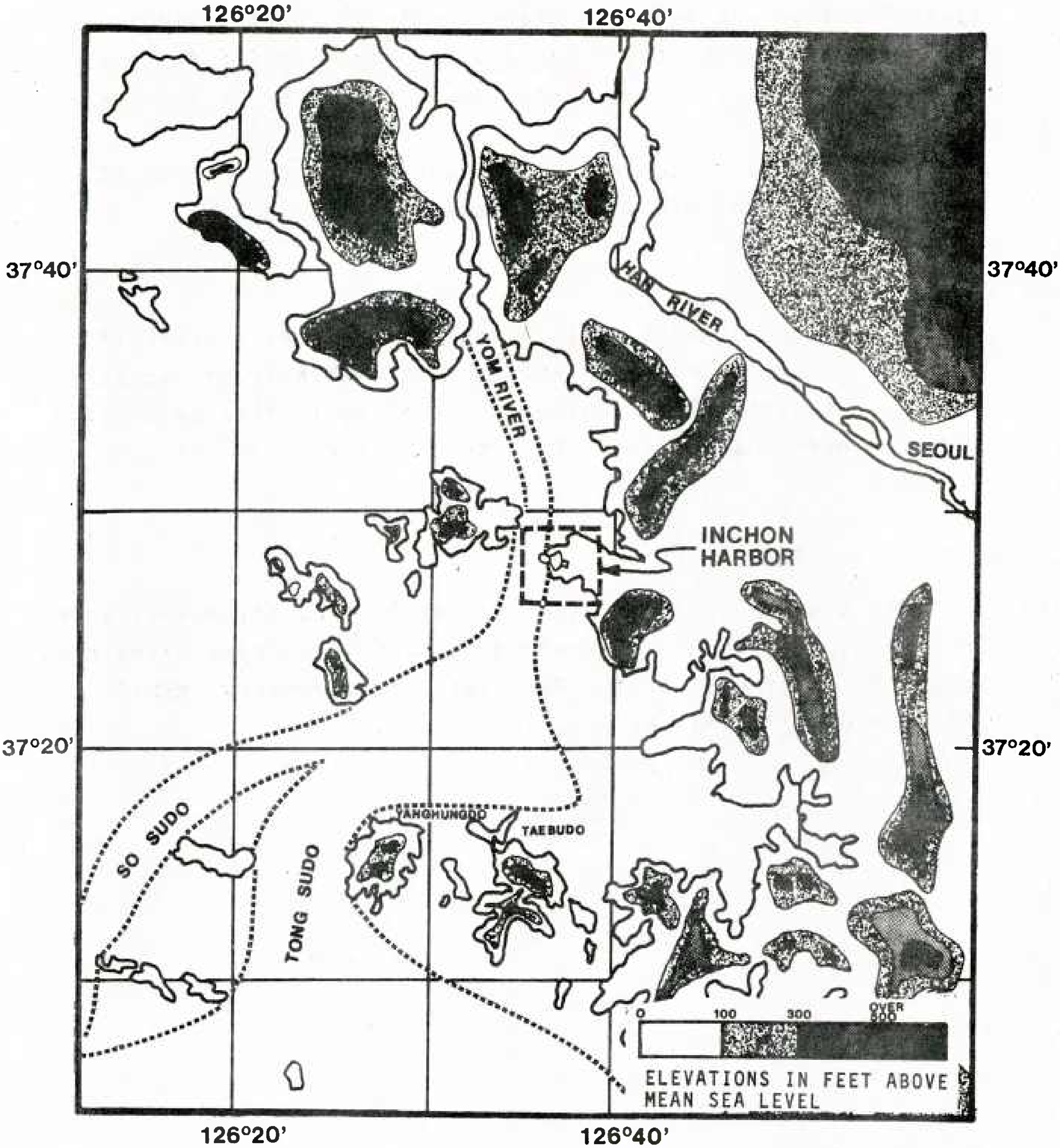


Figure 5. Mesoscale topography and geographic location of Inchon harbor.

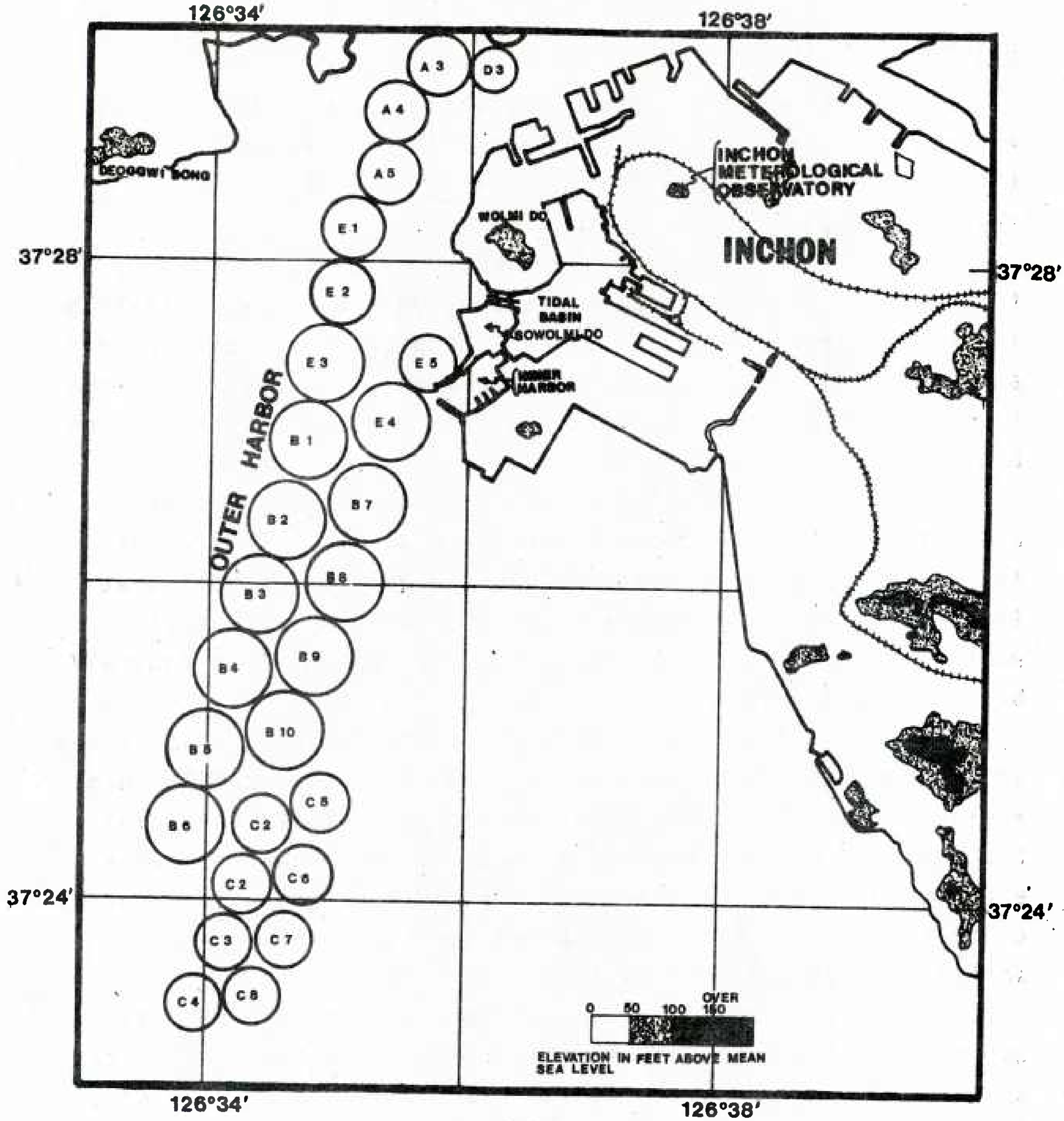


Figure 6. Inchon harbor and local topography.

# 5. TROPICAL CYCLONES AFFECTING INCHON

## 5.1 CLIMATOLOGY

For the purpose of this study any tropical cyclone that approaches within 180 n mi of Inchon is considered to be a threat to the harbor and will be designated as a "threat" tropical cyclone.

Figure 7 gives the monthly summary by 5-day periods of the "threat" tropical cyclones during June-October, 1947-1973. In this 27-year period 36 "threat" tropical cyclones occurred, an average of 1.3 per year. Figure 7 also indicates that the typhoon season for Inchon extends from the end of June to the beginning of October.

Most of the "threat" tropical cyclones affect Inchon after they have passed the recurvature point. (This means that the "threat" tropical cyclone's direction of motion at the closest point of approach (CPA) to Inchon had a north-easterly component of motion.) This is indicated in Figure 7 by the shaded area.

Figure 8 displays the "threat" tropical cyclones according to the compass octant from which they approached the 180 n mi radius threat area. The circled numbers indicate the total that entered from an individual octant. The adjacent numbers express this as a percentage. It is evident that the majority of tropical cyclones (58%) entered the threat area from a sector extending from S to SW.

Table 2 indicates that out of the 36 "threat" tropical cyclones during June-October 1947-1973, 58% passed Inchon to the east while 42% passed to the west of Inchon. Therefore, the chance of having an approaching "threat" tropical cyclone pass to the east of Inchon is slightly greater than a "threat" tropical cyclone passage to the west of Inchon.

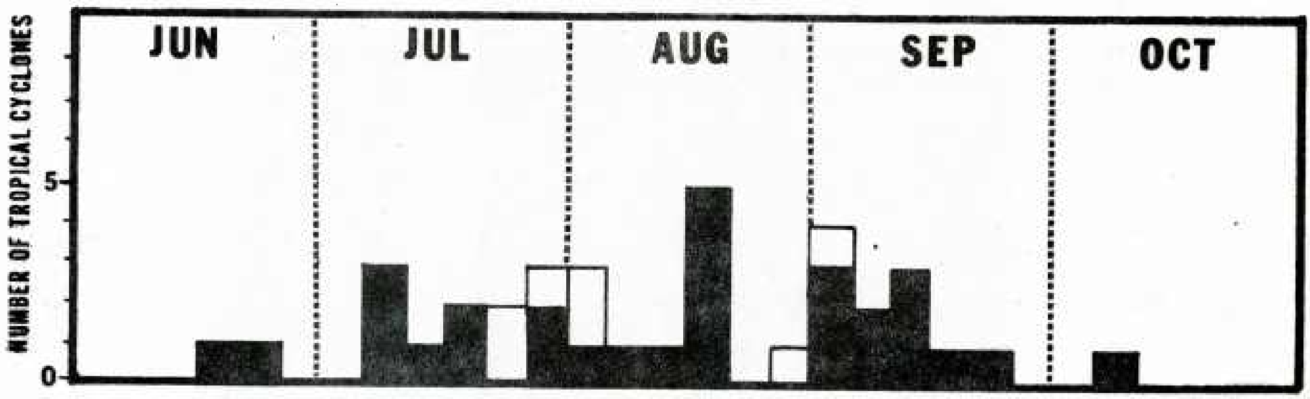


Figure 7. Frequency distribution of the number of tropical cyclones that passed within 180 n mi of Inchon. Subtotals are based on 5-day periods for tropical cyclones that occurred during 1947-1973. Shaded area indicates the number of recurving tropical cyclones per 5-day period.

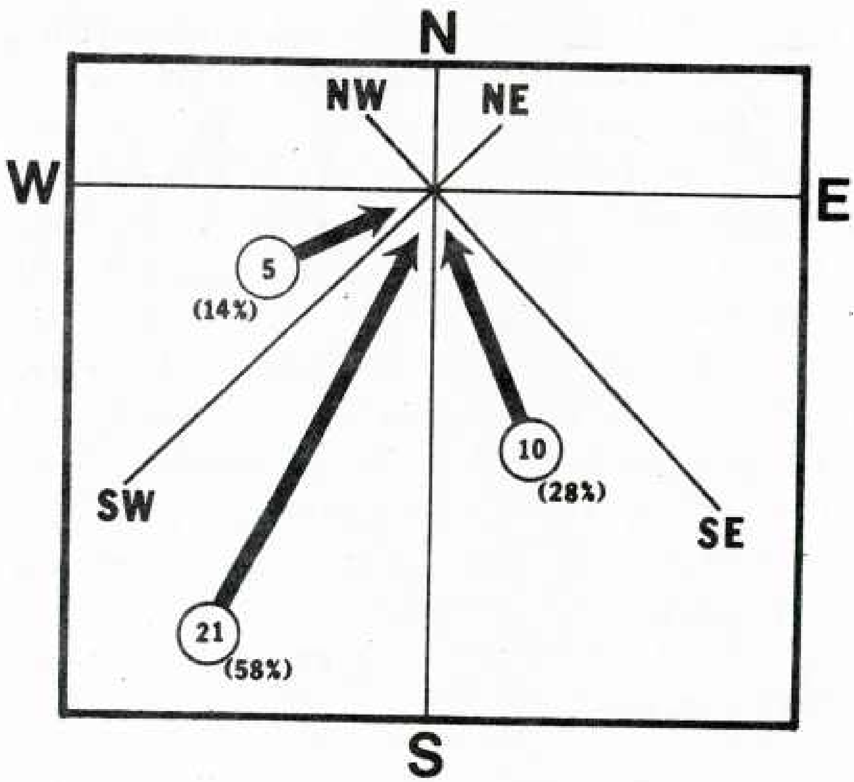


Figure 8. Directions from which tropical cyclones entered threat area (a 180 n mi radius circle centered at Inchon) during the period June-October, 1947-1973. Numbers circled indicate the number of tropical cyclones that entered from each octant. This is expressed as a percentage adjacent to the circled number.

Table 2. "Threat" tropical cyclone passage relative to Inchon (June-October, 1947-1973).

| Month | Jun | Jul | Aug | Sep | Oct | Total | % |
|---|---|---|---|---|---|---|---|
| Passed east of Inchon | 2 | 6 | 5 | 7 | 1 | 21 | 58% |
| Passed west of Inchon | 0 | 5 | 6 | 4 | 0 | 15 | 42% |

Approximately one-third of the 36 "threat" tropical cyclones during June-October, 1947-1973 threatened Inchon after recurving over mainland China. This travel over land leaves the storm without the required contact with warm sea necessary for maintaining strong winds; in addition, the frictional effect of land further reduces the strong winds and the tropical cyclone weakens rapidly. When the tropical cyclone enters the Yellow Sea, it may intensify again given the proper SST regime. Based on an analysis of mean SST in the Yellow Sea (Robinson and Bauer, 1971), SST in excess of 78.8°F are found predominantly in August but may also exist during July and September. The wind intensity of tropical cyclones that entered the Yellow Sea from mainland China increased on an average by 20%.

Figures 9 to 13 are based on an analysis of "threat" tropical cyclones during June-October, 1947-1973. The solid lines represent percentage isolines of "threat". The dashed lines represent approximate approach times to Inchon, computed from average tropical cyclone speeds of movement for June-October (speeds of movement were derived from U.S. NWSED, Asheville, 1973). The average speed of movements are presented in Table 3.

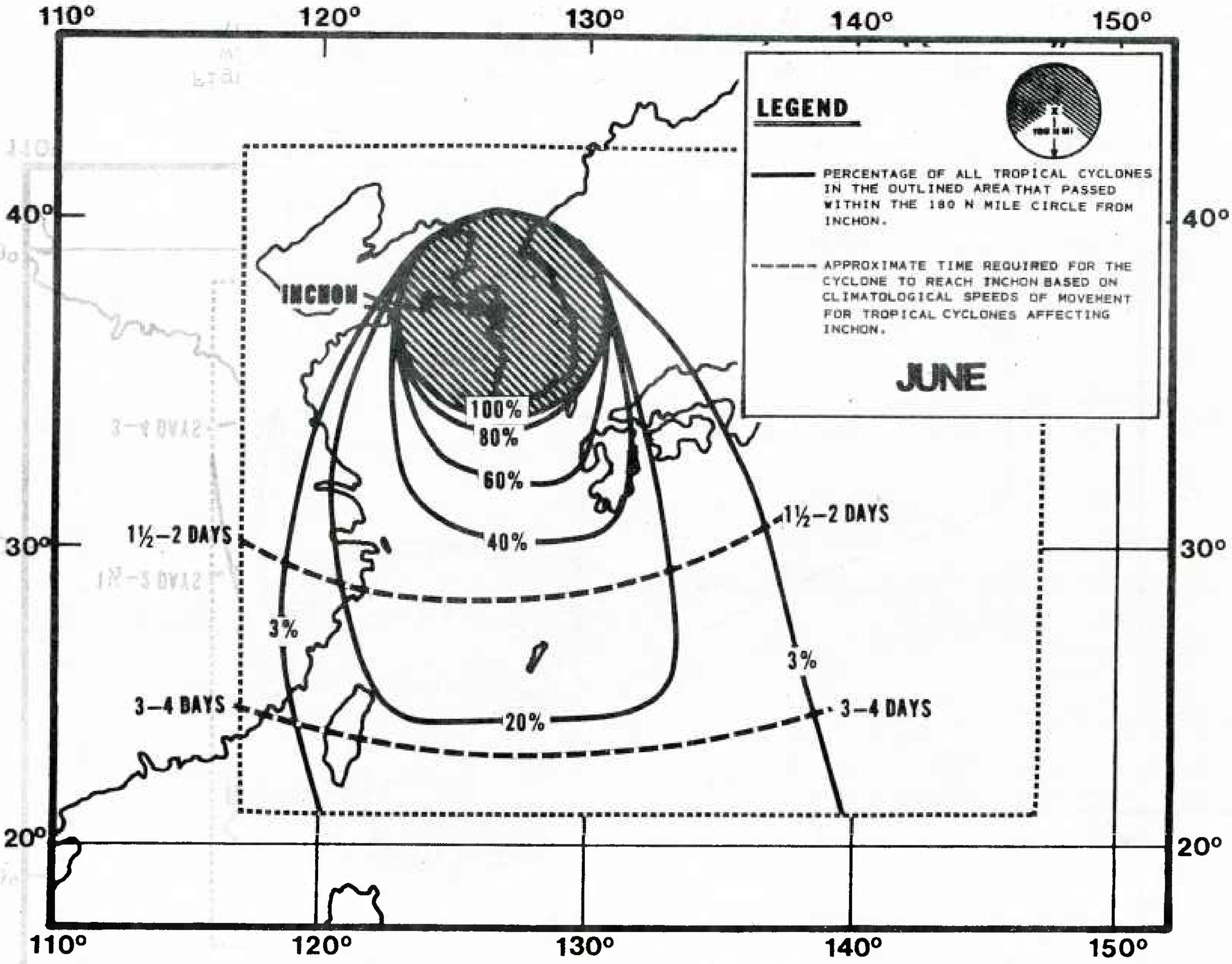


Figure 9. Percentage of tropical cyclones that passed within 180 n mi of Inchon for the month of June (based on June-October, data from 1947-1973).

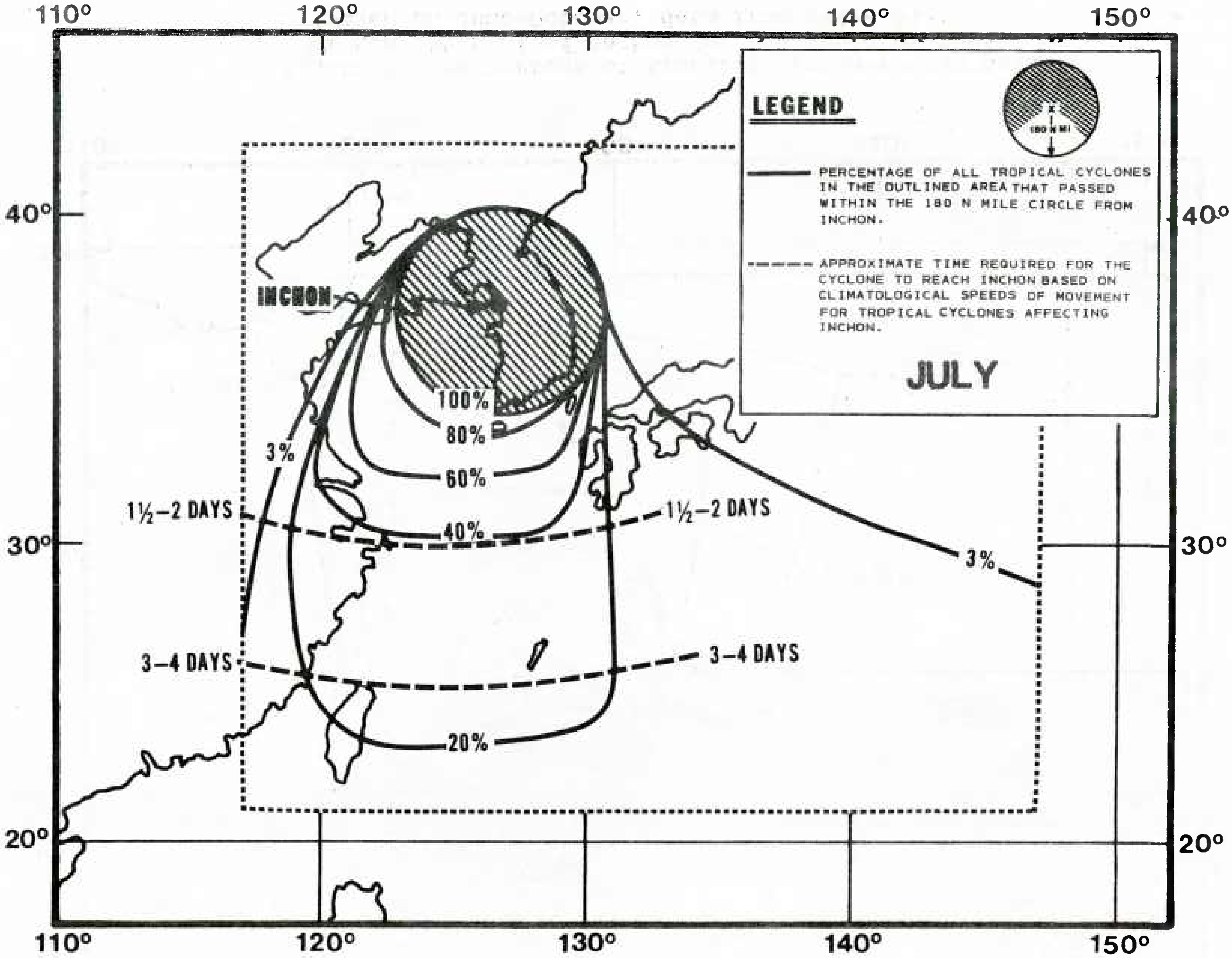


Figure 10. Percentage of tropical cyclones that passed within 180 n mi of Inchon for the month of July (based on June-October data from 1947-1973).

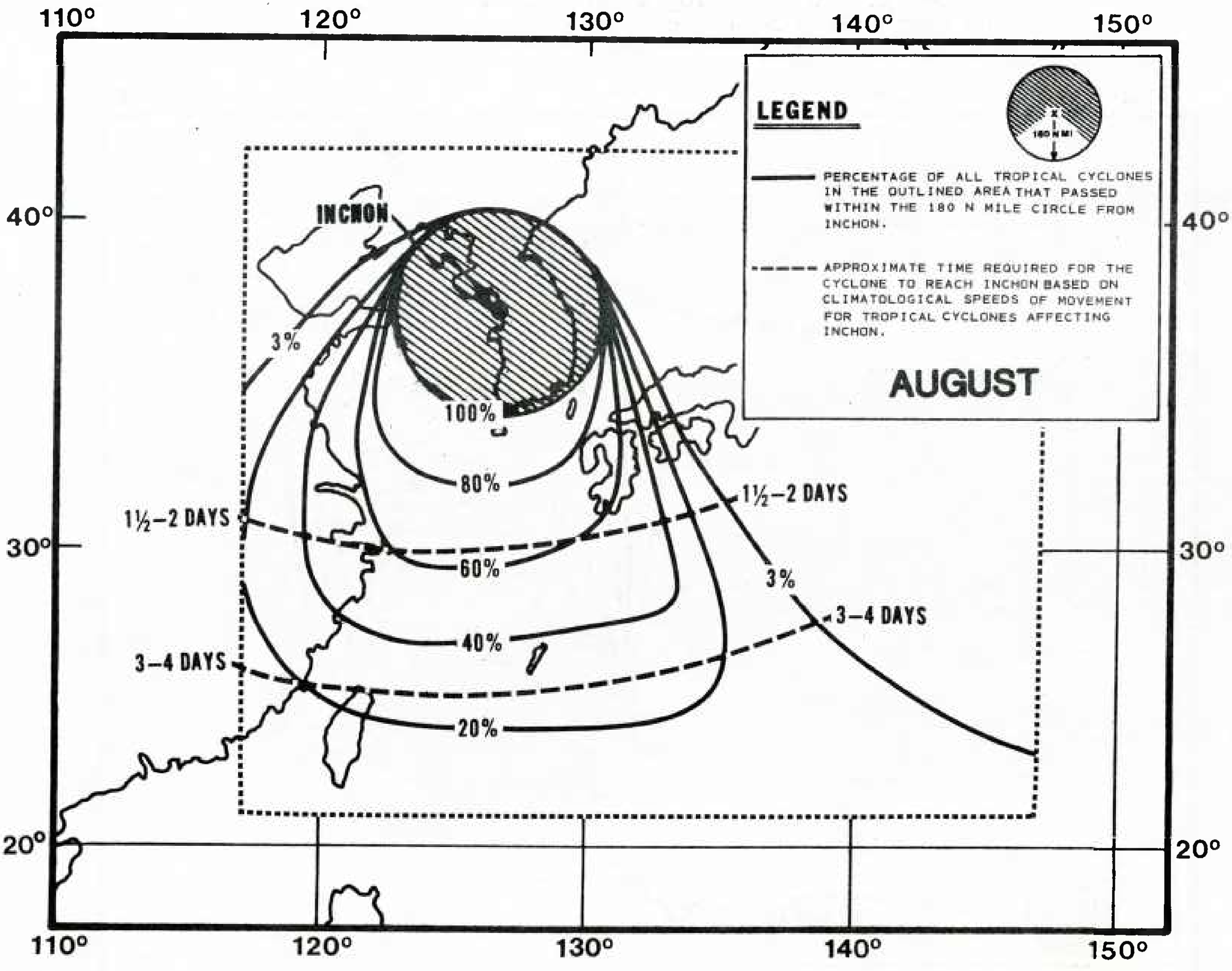


Figure 11. Percentage of tropical cyclones that passed within 180 n mi of Inchon for the month of August (based on June-October data from 1947-1973).

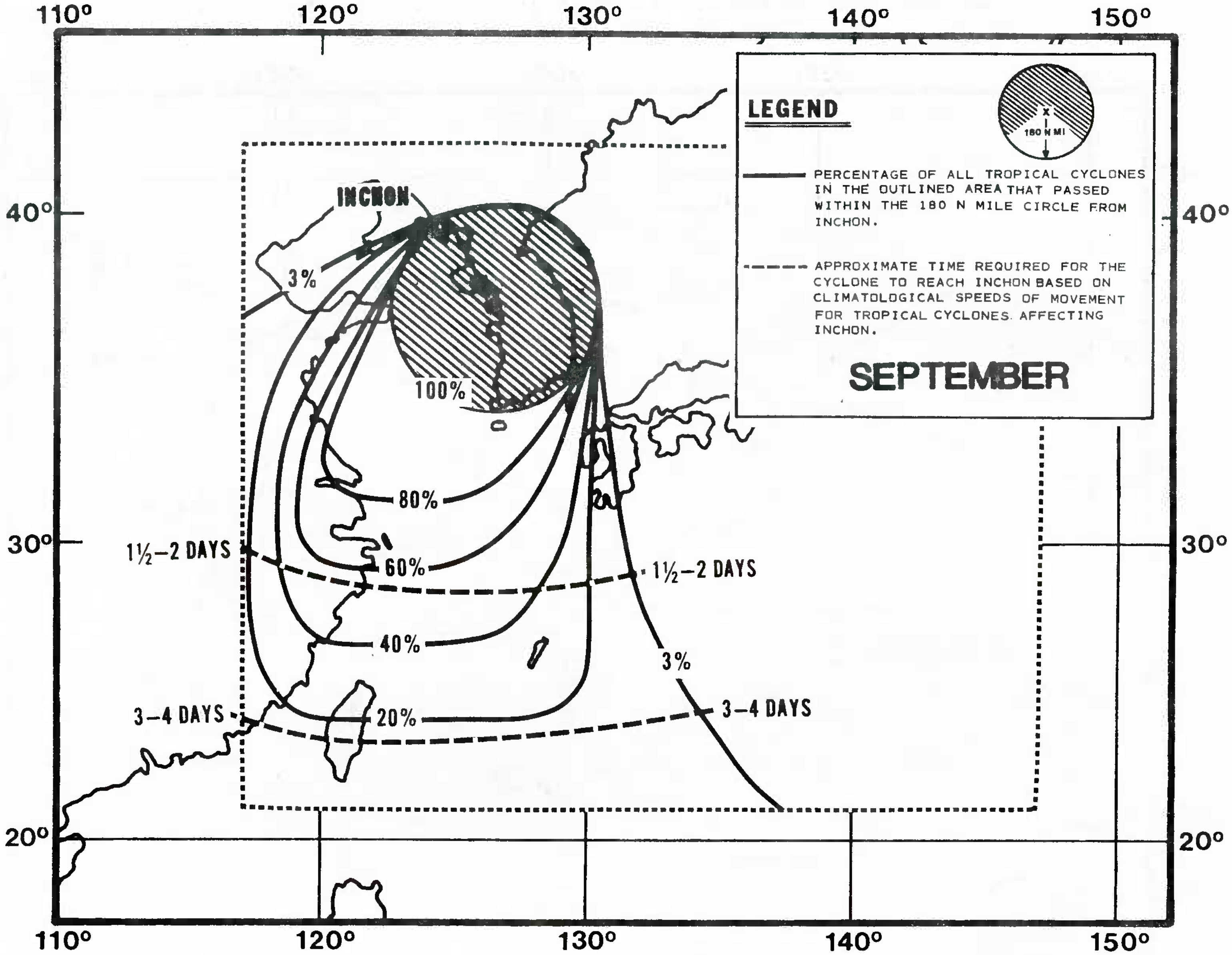


Figure 12. Percentage of tropical cyclones that passed within 180 n mi of Inchon for the month of September (based on June-October data from 1947-1973).

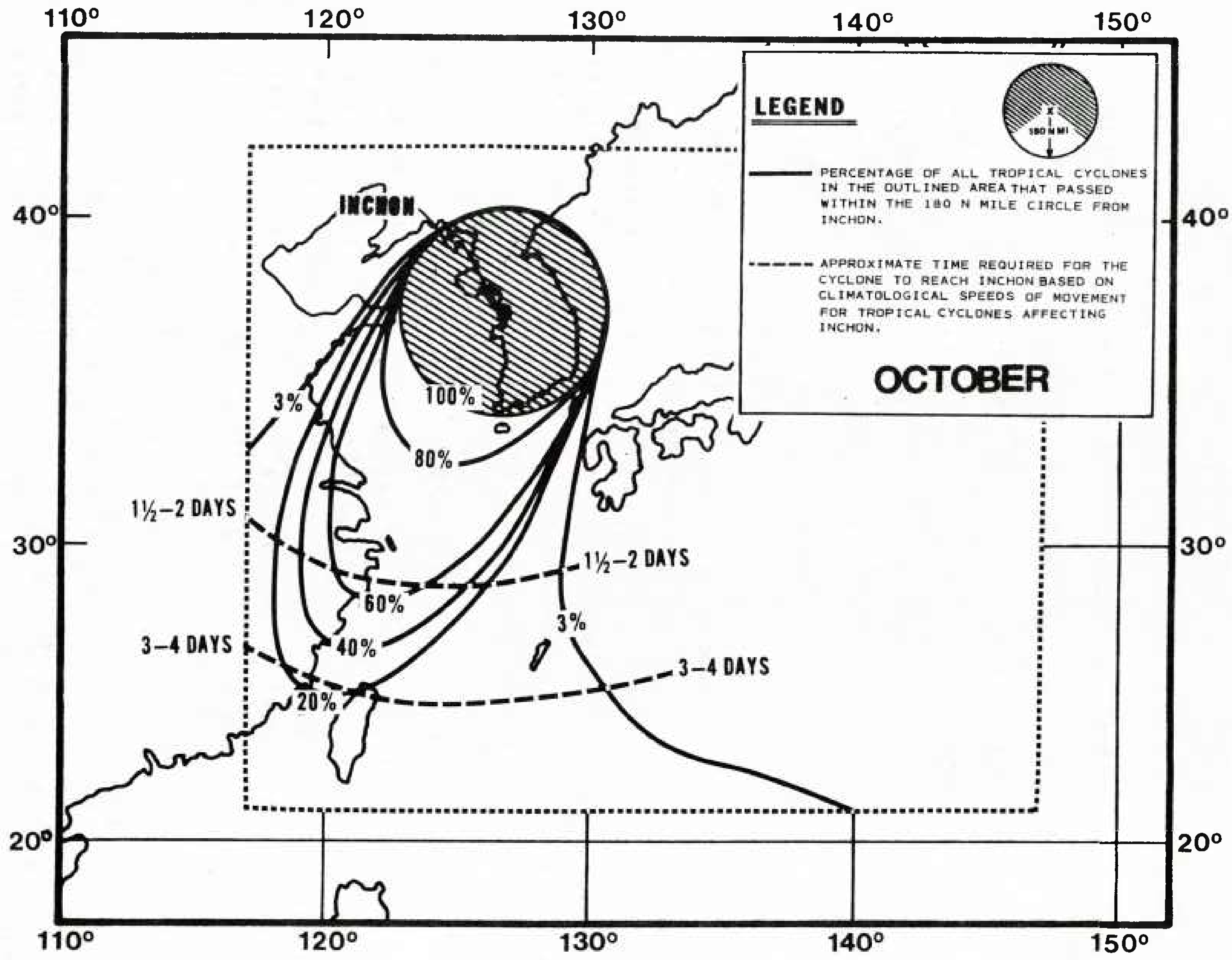


Figure 13. Percentage of tropical cyclones that passed within 180 n mi of Inchon for the month of October (based on June-October data from 1947-1972).

Table 3. Listing of June-October average climatological speeds of tropical cyclones affecting Inchon by 5-degree latitude bands.

| Latitude Band (°N) | Average Forward Speed of Movement Jun | Jul | Aug | Sep | Oct | Average of the 5 Months (kt) |
|---|---|---|---|---|---|---|
| 35-40 N | 25 | 20 | 18 | 23 | 23 | 21.8 |
| 30-35 | 20 | 13 | 14 | 18 | 17 | 16.4 |
| 25-30 | 15 | 10 | 11 | 13 | 13 | 12.4 |
| 20-25 | 11 | 10 | 11 | 11 | 12 | 11.0 |
| 15-20 | 9 | 9 | 10 | 11 | 11 | 10.0 |

Figures 9-13 should prove useful in determining the probability of a tropical cyclone "threatening" Inchon from a given position within the grid. For example, a tropical cyclone located at 24N, 130E in June (see Figure 9) will have a 20% probability of passing within 180 n mi of Inchon, and it could reach Inchon in less than 3 days.[3]

## 5.2 WIND AND TOPOGRAPHICAL EFFECTS

From analyses of the "threat" tropical cyclone tracks (Figures 14-18), it is apparent that tropical cyclones producing gale force winds ($\geq$ 34 kt) in Inchon can pass either to the east or west of Inchon. If the tropical cyclone path is to the east of Inchon some of its intensity will be lost

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[3]A word of caution on Figures 9 and 13: Figure 9 is based on analyses of 2 threat tropical cyclone occurrences while Figure 13 is based on analysis of only 1 threat tropical cyclone occurrence. Due to the limited size of the data base caution must be exercised when using these figures.

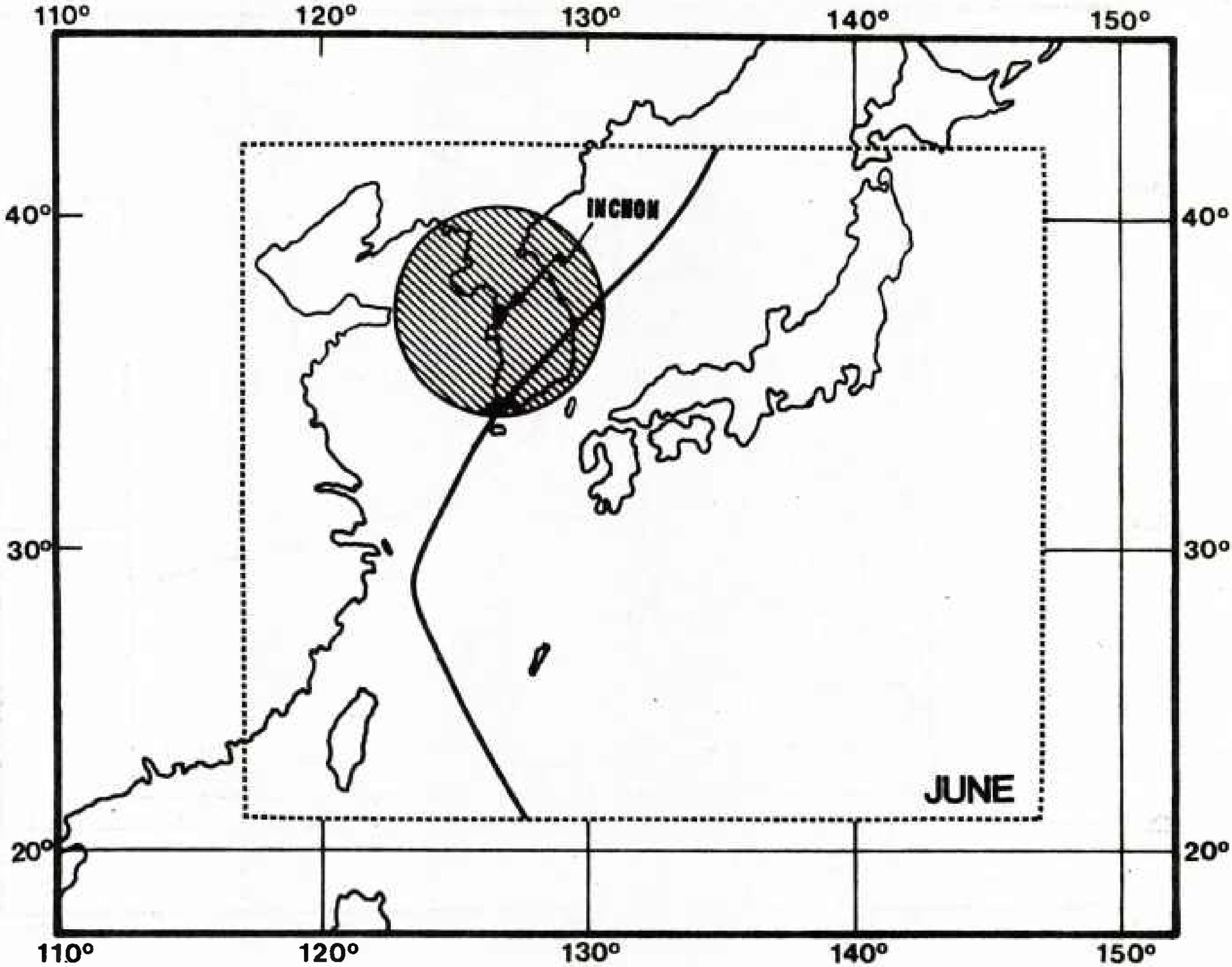


Figure 14. Track of tropical cyclone approaching within 180 n mi of Inchon during the 22-year period, 1952-73 for June. Solid line indicates tropical cyclones passing within 180 n mi of Inchon but not producing winds $\geq$ 34 kt at Inchon.

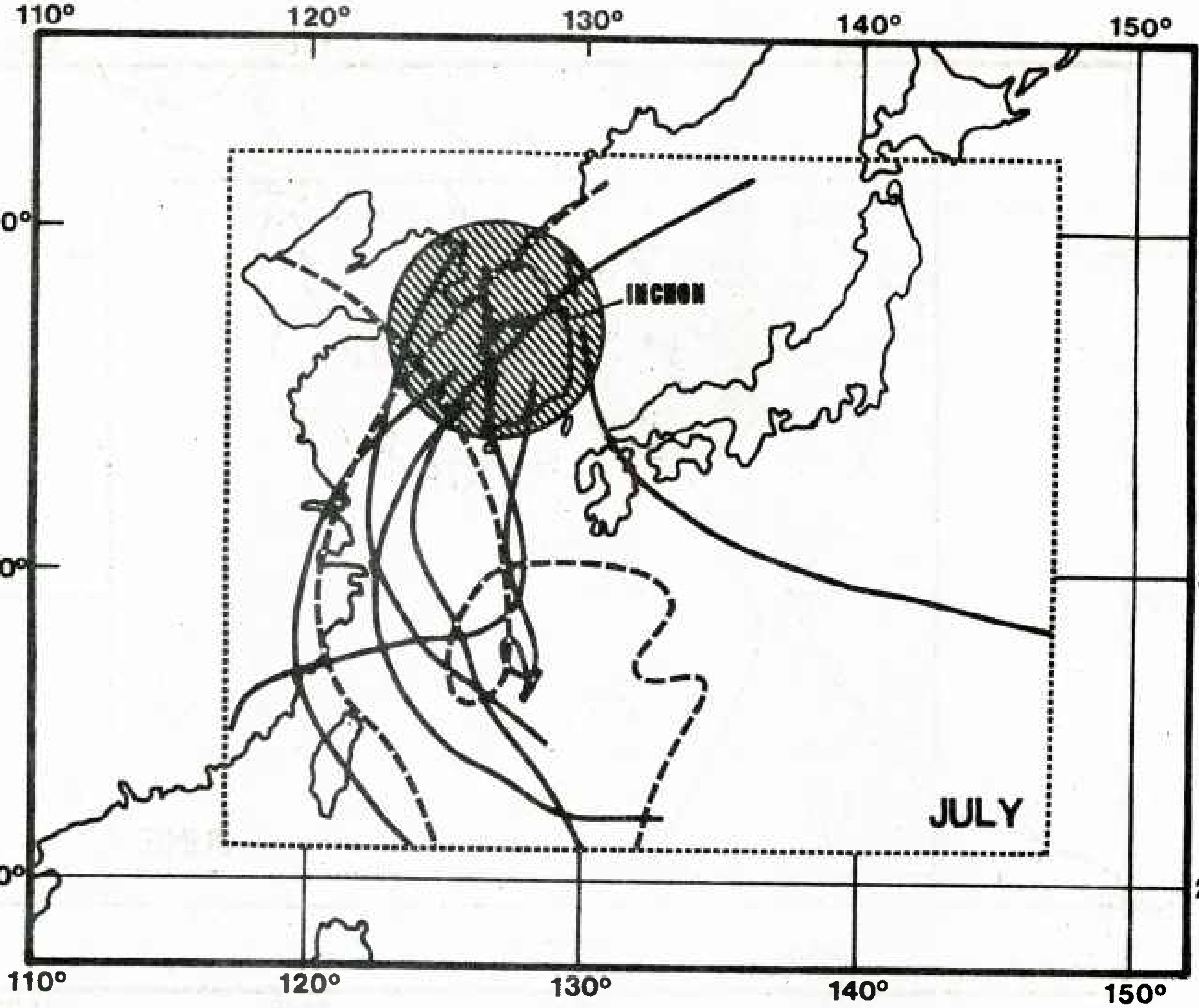


Figure 15. Tracks of tropical cyclones approaching within 180 n mi of Inchon during the 22-year period 1952-73 for July. Dashed line indicates tracks of tropical cyclones that produced winds $\geq$ 34 kt at Inchon. Solid line indicates tropical cyclones passing within 180 n mi of Inchon but not producing winds $\geq$ 34 kt at Inchon.

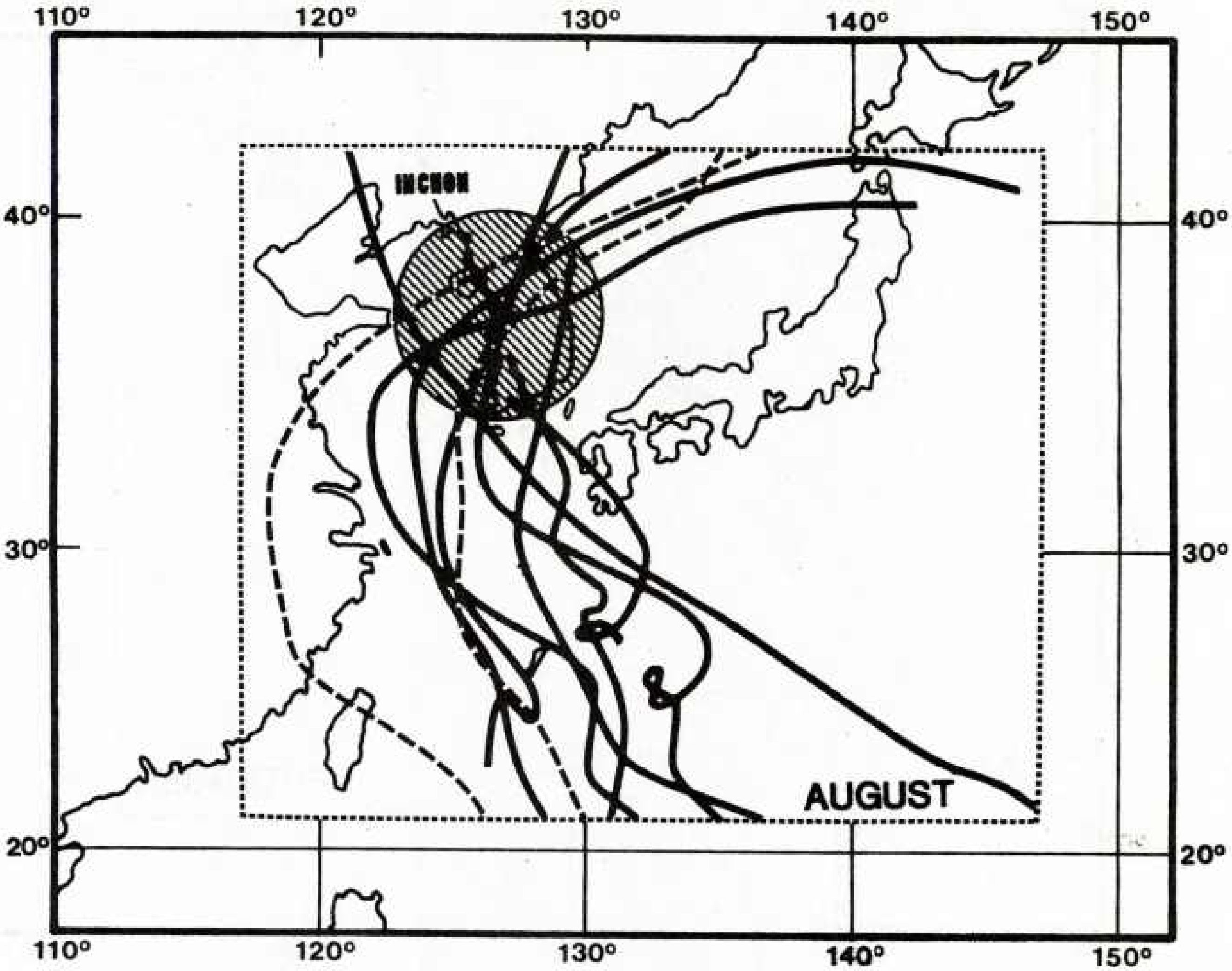


Figure 16. Tracks of tropical cyclones approaching within 180 n mi of Inchon during the 22-year period 1952-73 for August. Dashed line indicates tracks of tropical cyclones that produced winds $\geq$ 34 kt at Inchon. Solid line indicates tropical cyclones passing within 180 n mi of Inchon but not producing winds $\geq$ 34 kt at Inchon.

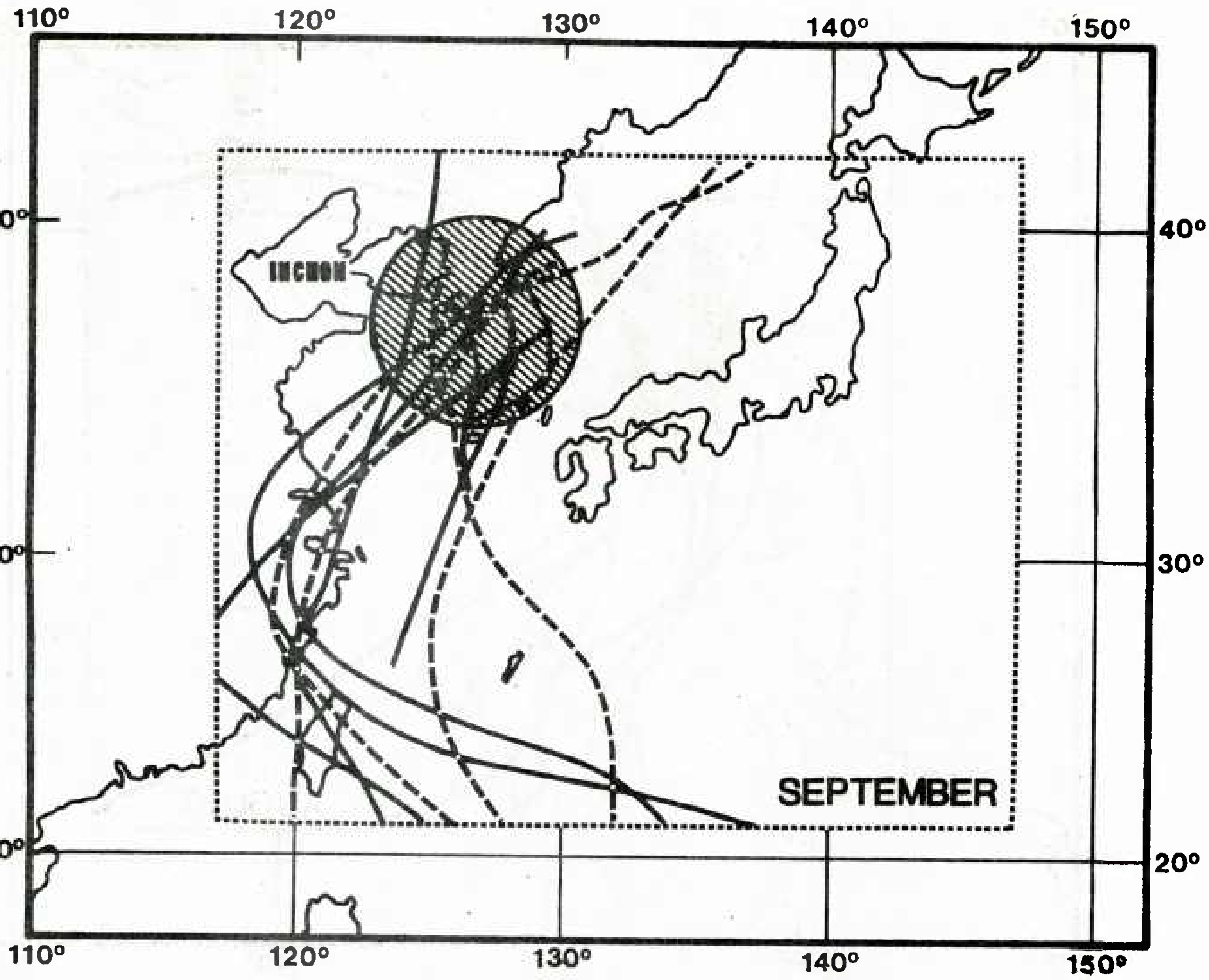


Figure 17. Tracks of tropical cyclones approaching within 180 n mi of Inchon during the 22-year period 1952-73 for September. Dashed line indicates tracks of tropical cyclones that produced winds ≥ 34 kt at Inchon. Solid line indicates tropical cyclones passing within 180 n mi of Inchon but not producing winds ≥ 34 kt at Inchon.

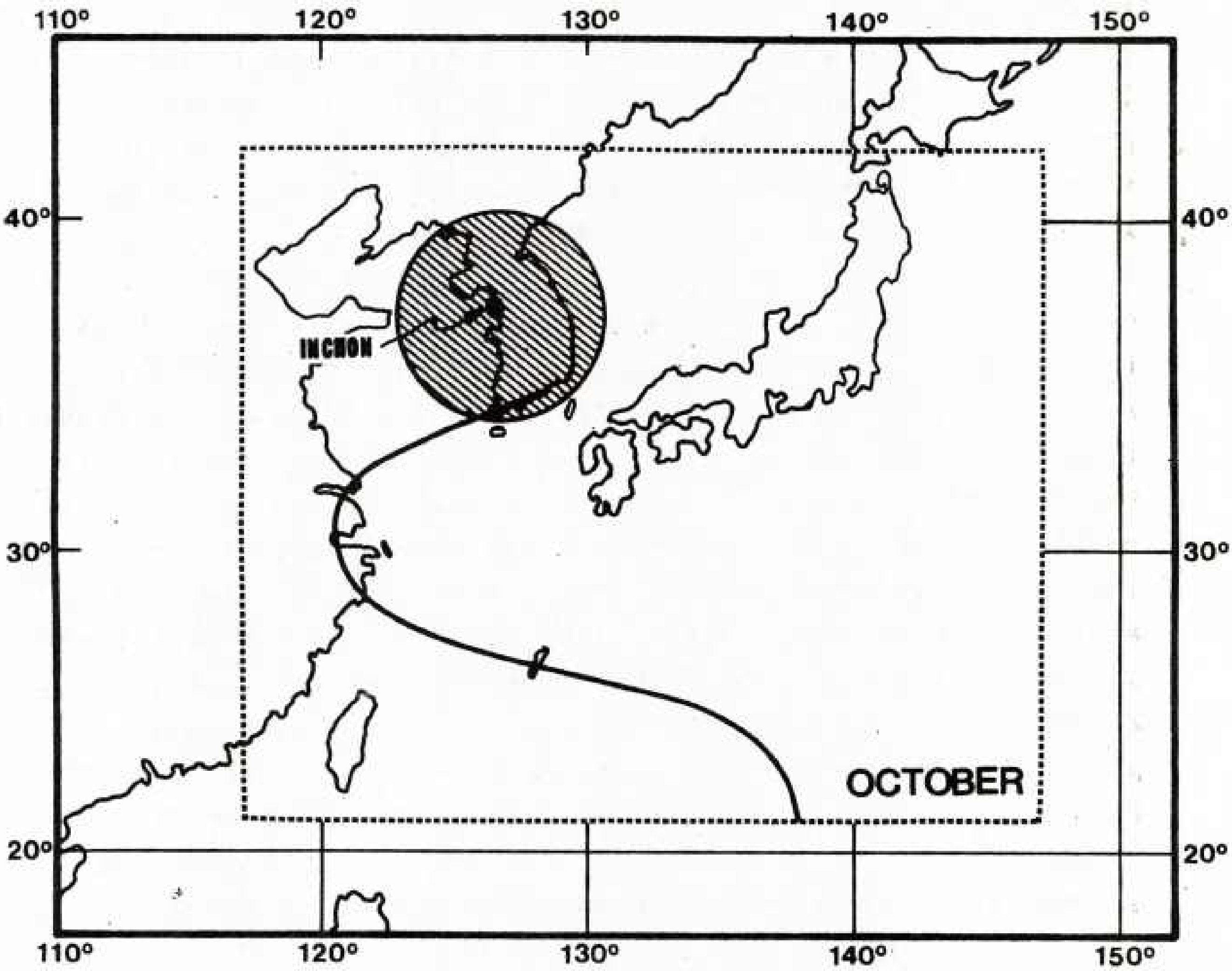


Figure 18. Track of the single tropical cyclone which approached within 180 n mi of Inchon during the 22-year period 1952-73 for October. Solid line indicates the tropical cyclone passed within 180 n mi of Inchon but did not produce winds $\geq$ 34 kt at Inchon.

through interaction with the land. Tropical cyclone passage to the east will produce northerly winds in Inchon as a result of the tropical cyclones' counterclockwise rotation. The land masses to the north and northeast will provide protection from the winds. Figures 14-18 indicate that only three out of eight tropical cyclones producing gale force winds ($\geq$ 34 kt) passed east of Inchon.

To determine the extent to which "threat" tropical cyclones produced strong winds ($\geq$ 22 kt) or gale force winds ($\geq$ 34 kt) in Inchon, the wind observations from the Inchon Meteorological Observatory (37°28'31"N, 126°37'38"E, see Figure 6) located on top of a 267 ft hill were analyzed. Since this is the highest peak in Inchon proper, winds recorded here are representative of wind conditions existing in the harbor. The hourly wind observations from this recording site were analyzed during June-October, 1952-1973. Table 4 groups the 31 tropical cyclones that "threatened" Inchon during this 22-year period according to the wind intensity that they produced in Inchon. Only twenty-four percent of the "threat" tropical cyclones produced gale force ($\geq$ 34 kt) winds in Inchon. It should be noted that the maximum sustained wind ever observed during this period was less than 50 kt.

Table 4. Extent to which "threat" tropical cyclones affected Inchon during June-October, 1952-1973.

| | | |
|---|---|---|
| Number of tropical cyclones that "threatened" Inchon | 31 | % |
| Number of "threat" tropical cyclones resulting in strong ($\geq$ 22 kt) winds in Inchon | 14 | 42% |
| Number of "threat" tropical cyclones resulting in gale force ($\geq$ 34 kt) winds in Inchon | 8 | 24% |

Figure 19 shows the positions of "threat" tropical cyclone centers when strong winds ($\geq$ 22 kt) were first and last recorded at the Inchon Meteorological Observatory. It is apparent that "threat" tropical cyclones generally produce winds $\geq$ 22 kt in Inchon when north of 35° latitude.

Figure 20 shows tropical cyclone center positions when gale force ($\geq$ 34 kt) winds were first and last recorded at the Inchon Meteorological Observatory. It can be seen that winds $\geq$ 34 kt generally do not begin until the storm is north of 37° latitude and that no "threat" tropical cyclones to the southeast of Inchon produced gale force winds.

## 5.3 WAVE ACTION

Maximum wave action is associated with a typhoon passing to the west since this places Inchon in the right or "dangerous" semicircle of the typhoon. The greater relative wind in this area generates waves which tend to be more destructive. The maximum wave heights that can be expected with typhoon strength winds ($\geq$ 64 kt) in Inchon Harbor are presented in Table 5.[4]

Table 5. Maximum wave heights that can be expected with typhoon strength winds ($\geq$ 64 kt) in the Outer Harbor (northern and southern part) and Tidal Basin of Inchon.

| LOCATION | OUTER HARBOR Northern Part | OUTER HARBOR Southern Part | TIDAL BASIN |
|---|---|---|---|
| Winds generally from the north (tropical cyclone passage east of Inchon | 5 ft | 6 ft | 4 ft |
| Winds generally from the south (tropical cyclone passage west of Inchon | 8 ft | 7 ft | 4 ft |

[4]Based on Forecasting Curves for Shallow-Water Waves from U.S. Army Coastal Engineering Research Center, 1973: "Shore Protection Manual (Volume I)."

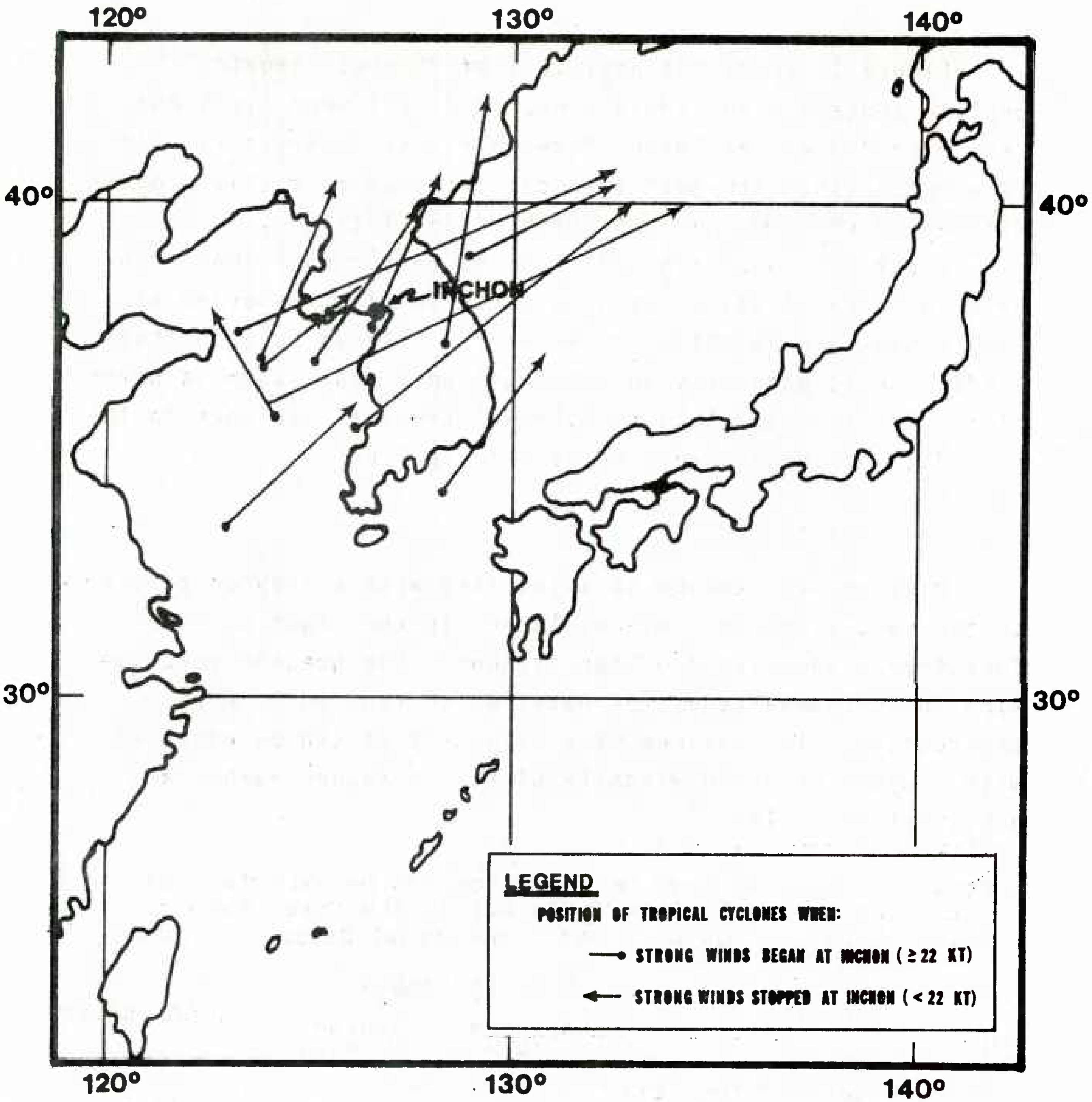


Figure 19. Positions of tropical cyclone centers when ≥22 kt winds first and last occurred at Inchon (based on June-October data from the years 1952-1973).

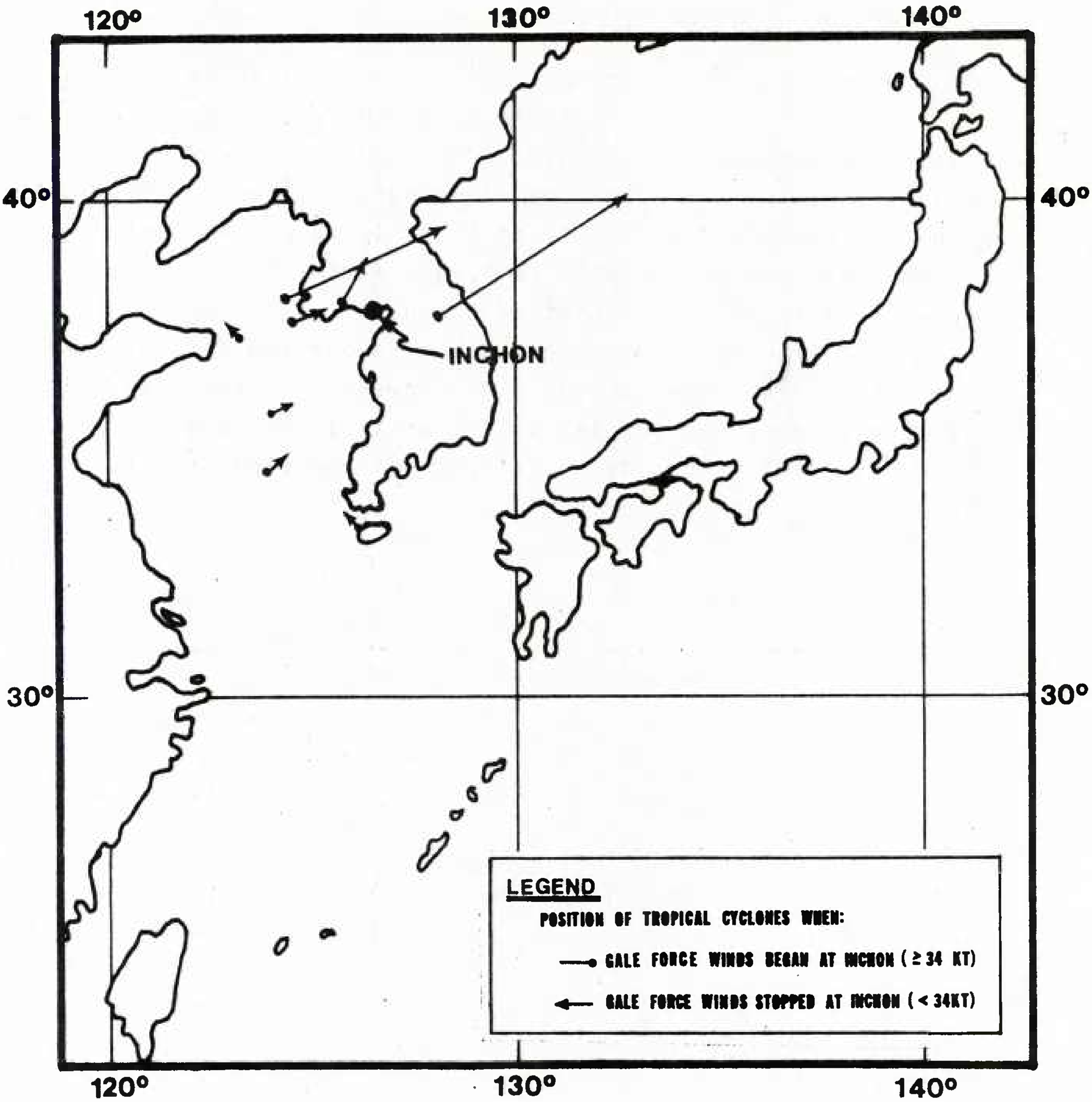


Figure 20. Positions of tropical cyclone centers when $\geq$34 kt winds first and last occurred at Inchon (based on June-October data from the years 1952-1973).

## 5.4 STORM SURGE AND TIDES

When a tropical cyclone crosses a coastline, a rise in water level may occur. This is caused by wind stress on the water surface and the effects of atmospheric pressure reduction. The height of the storm surge is dependent on the tropical cyclone track. If the track is to the west of Inchon, the peak surge will be large; while the opposite is true for a track to the east of the port.

The large tidal range of Inchon Harbor (30 ft) may make the surge effect seem negligible. However, if the tropical cyclone is forecast to pass to the west of Inchon and this coincides with high tide an extremely large rise in water level can be anticipated.

# 6. PREPARATION FOR HEAVY WEATHER AT INCHON

## 6.1 TROPICAL CYCLONE WARNINGS

It is essential to recognize that the approach of a typhoon is usually signaled by the following indicators:[5]

(1) Heavy swell (in front and to the right of the storm).

(2) Greater than normal amounts of high cirrus clouds known as "mackerel sky."

(3) Irregular or pumping action of barometer followed by a steady drop. The diurnal pressure variation effect (high at 1000 and 2200 local time, low at 0400 and 1600 local time) must be kept in mind. When the diurnal variation is no longer evident, the storm is close.

Tropical cyclone warnings including 24-, 48-, and 72-hr forecasts are issued by the Fleet Weather Central/Joint Typhoon Warning Center (FWC/JTWC), Guam. When the initial warning of a tropical depression, storm or typhoon is received, a running plot of the following should be maintained:

(1) Ship's position.

(2) Actual and forecast tropical cyclone center position.

(3) Area of dangerous winds (30 kt and above).

Appendix 1 to Annex H of CINCPACFLT OPORD 201-(YR) describes how to calculate the "Danger Area" of a tropical cyclone. A copy of this pertinent section is included in Appendix C of this report.

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[5] From CINCPACFLT OPORD 201, H-1-5.

An average 24-hr forecast position error of 135 n mi is commonly used. Burroughs and Brand (1972) found that the average 24-hr forecast error for recurving typhoons is 141 n mi. For forecast positions verifying <u>after</u> the point of recurvature, the error was 165 n mi. Since most of the "threat" tropical cyclones affecting Inchon are past the point of recurvature, it may be prudent to use a radius greater than 135 n mi when determining the danger area. The criteria for setting local heavy weather readiness conditions are reprinted in Appendix C of this report.

## 6.2 EVASION

Evasion from Inchon Harbor is the recommended course of action <u>if shelter in the tidal basin is not available</u>. Remaining at anchor in the Outer Harbor is not recommended for the following reasons:

(1) The currents in the Outer Harbor may exceed 3 kt.

(2) The holding action of the Outer Harbor bottom is good only in the southern anchorages.

(3) At least one ship has run aground after dragging anchor in the northern part of the Outer Harbor.

During a 22-year period, the maximum sustained wind reported in Inchon resulting from a tropical cyclone was less than 50 kt. This is in part due to the fact that most of the tropical cyclones affecting Inchon are dissipating in intensity. Therefore, it is felt that the best evasion procedure for ships to follow is to head for the Yellow Sea and then maneuver in such a manner as to place the ship in the navigable semicircle. Since the waters near Inchon Harbor are restricted and the currents in the approach channels may be quite strong, especially in So Sudo Channel (see Figure 5) where current velocities up to 8 kt have been reported, evasion must

commence early. Given a strong current, a ship steaming at 10 kt will require approximately 6 hr to clear the Outer Harbor and reach the open water of the Yellow Sea.

Figure 21 shows the tropical cyclone threat axis for Inchon. The area enclosed within the arrow represents a 30% or greater probability of a tropical cyclone coming within 180 n mi (indicated by the hatched circle) of Inchon. To facilitate early action, the following timetable (in conjunction with Figure 21) has been established:

I. An existing tropical cyclone moves into or development takes place in area "A" with forecast movement toward Korea.

   a. Review material condition of ship. A sortie may be desirable within 2 days.

   b. Reconsider any maintenance that would render the ship incapable of getting underway within 48 hours.

II. Tropical cyclone enters area "B" with forecast movement toward Inchon.

   a. Operational plans should be made in the event of a sortie.

   b. Reconsider any maintenance that would render the ship incapable of getting underway within 24 hours.

III. Tropical cyclone enters area "C" moving toward Inchon.

   a. Execute evasion plans made in previous steps.

An alternative evasion procedure which is used by the large vessels of the ROK Navy is to anchor just north of Taebu Do and Yanghung Do (see Figure 5). Unfamiliarity with the waters in this vicinity and proximity to land masses may make this evasion technique unattractive to commanding officers.

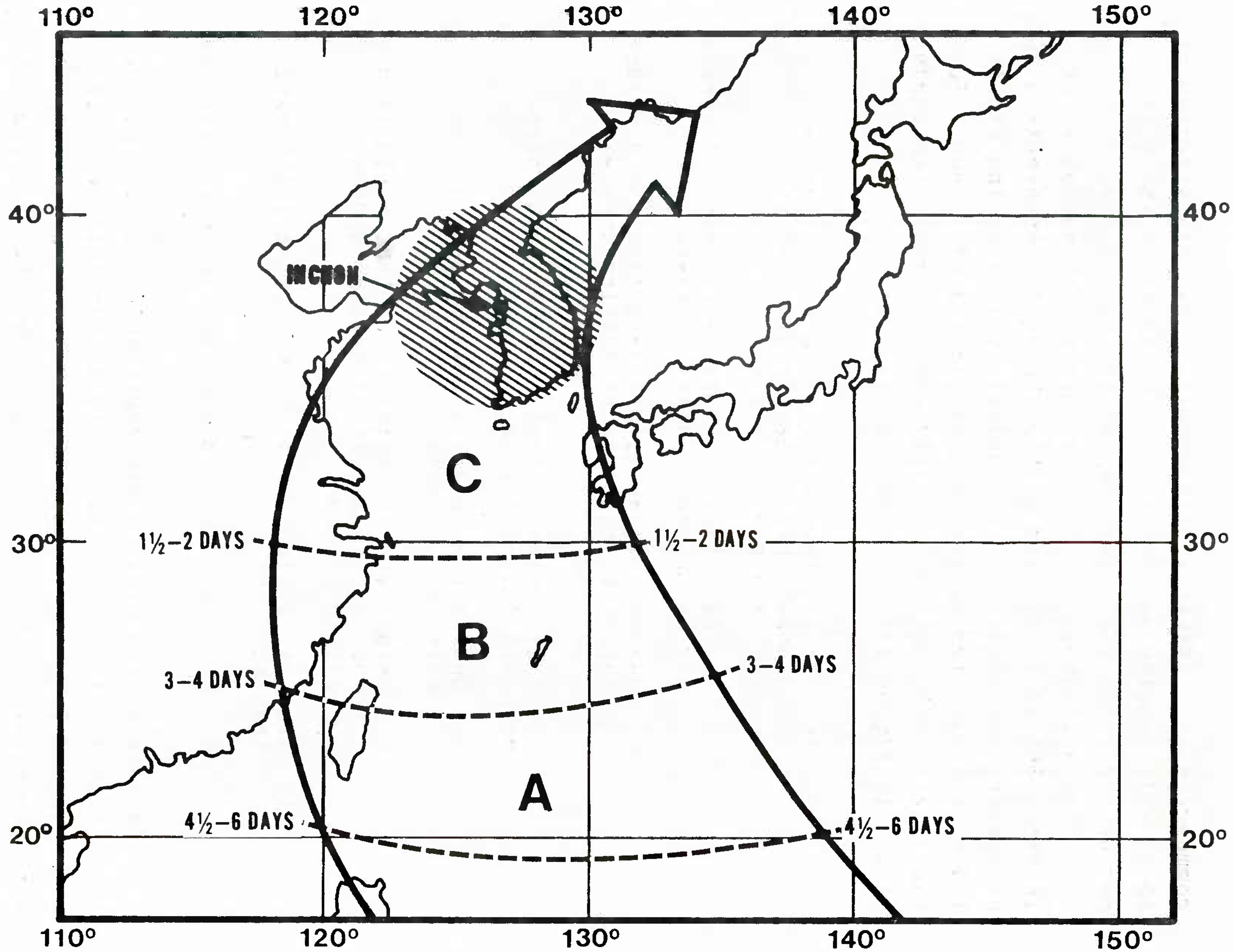


Figure 21. Tropical cyclone threat axis for Inchon. Approach times are based on average climatological speeds of movements for tropical cyclones affecting Inchon.

## 6.3 REMAINING IN PORT

Remaining in port is recommended only if shelter is available in the tidal basin. If shelter is not available in the tidal basin, evasion from Inchon is recommended (see section 6.2). The tidal basin provides good protection from "threat" tropical cyclones for the following reasons:

(1) Good protection is provided by the surrounding topography from strong winds. The maximum sustained wind recorded at Inchon resulting from a tropical cyclone was less than 50 kt.

(2) The tidal basin provides excellent protection from high seas. The maximum wave height that can be expected is 4 ft.

To facilitate early action the following timetable in conjunction with Figure 21 has been established:

I. An existing tropical cyclone moves into or development takes place in area "A" with forecast movement toward Korea.

   a. Review material conditions of ship. Movement to the tidal basin may be desirable in 2-4 days.

   b. Reconsider any maintenance that would render the ship incapable of getting underway within 48 hours.

II. Tropical cyclone enters area "B" with forecast movement toward Inchon.

   a. Determine if berth is available in tidal basin. Plans should be made for move to the tidal basin. Recall that tidal basin can only be entered at slack tide.

   b. Reconsider any maintenance that would render the ship incapable of making the move to the tidal basin within 24 hours.

III. Tropical cyclone enters area "C" moving toward Inchon.

a. Execute plans for movement to the tidal basin.

The ROK Navy utilizes the B anchorages in the southern part of the Outer Harbor as typhoon anchorages for medium-size vessels such as DDG's, DD's, etc. The holding action of the harbor bottom is good here and there have been no reports of ships dragging anchor in this area. However, due to the strong currents (in excess of 3 kt) and the great tidal range, anchoring in the Outer Harbor should only be considered if there is no berth available in the tidal basin and it is too late to evade the tropical cyclone in the Yellow Sea. Under no circumstances should the anchorages in the northern part of the Outer Harbor be utilized during the passage of a tropical cyclone.

## 7. CONCLUSIONS FOR INCHON

The conclusion reached by this study is that Inchon Harbor is a typhoon haven only if a ship is berthed in the tidal basin. If this is not possible, evasion in the Yellow Sea is recommended. Most of the tropical cyclones affecting Inchon are in the dissipating stage with central winds ranging generally between 45-60 kt. A well prepared ship should be able to ride this storm out at sea if it is positioned in the navigable semicircle.

# 8. PUSAN

## 8.1 LOCATION

Figure 22 shows the location of Pusan Harbor on the southeast coast of the Korean Peninsula at 35°06'N, 129°02'E.

## 8.2 PUSAN HARBOR

Pusan Harbor, Korea's principal deep water port, is divided by Yong-Do Island into a northern and southern harbor (see Figure 23). Both harbors are further divided into inner and outer harbors. North Harbor accommodates ocean-going vessels while South Harbor is used primarily by coastal vessels. Unless otherwise stated, reference to Pusan Harbor will specifically apply to North Harbor. An intensive construction program is presently underway in the North Harbor. This includes dredging of the fairway and construction of container and grain piers as indicated in Figure 24. Anchorages are available in the outer and inner harbors. With the exception of a few rocky patches in the Outer Harbor, good anchor holding action is available in a mud and sand bottom. The inner harbor is one of the few in Korea where deep-draft vessels can berth at piers.

The range of tides in Pusan Harbor is approximately 4 ft. In the narrow channels between Yong-Do Island (see Figure 23) and Pusan Harbor, tidal currents attain velocities of 3-4 kt.

## 8.3 TOPOGRAPHY

Pusan Harbor is well protected by hills in all directions except to the southeast and southwest where it faces the sea and to the north where the port opens into a valley (see Figure 23).

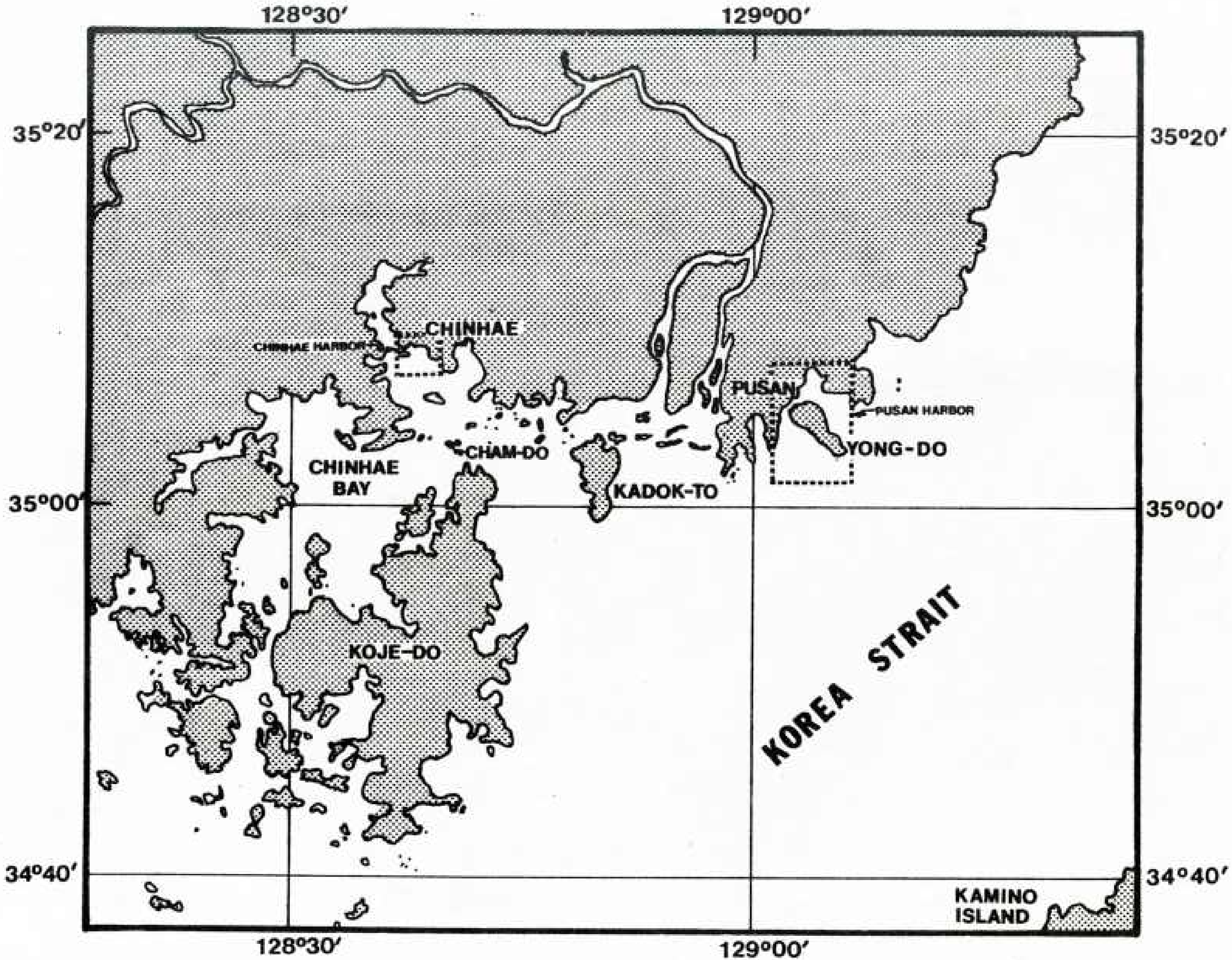


Figure 22. Southeastern tip of the Korean Peninsula showing location of Pusan and Chinhae.

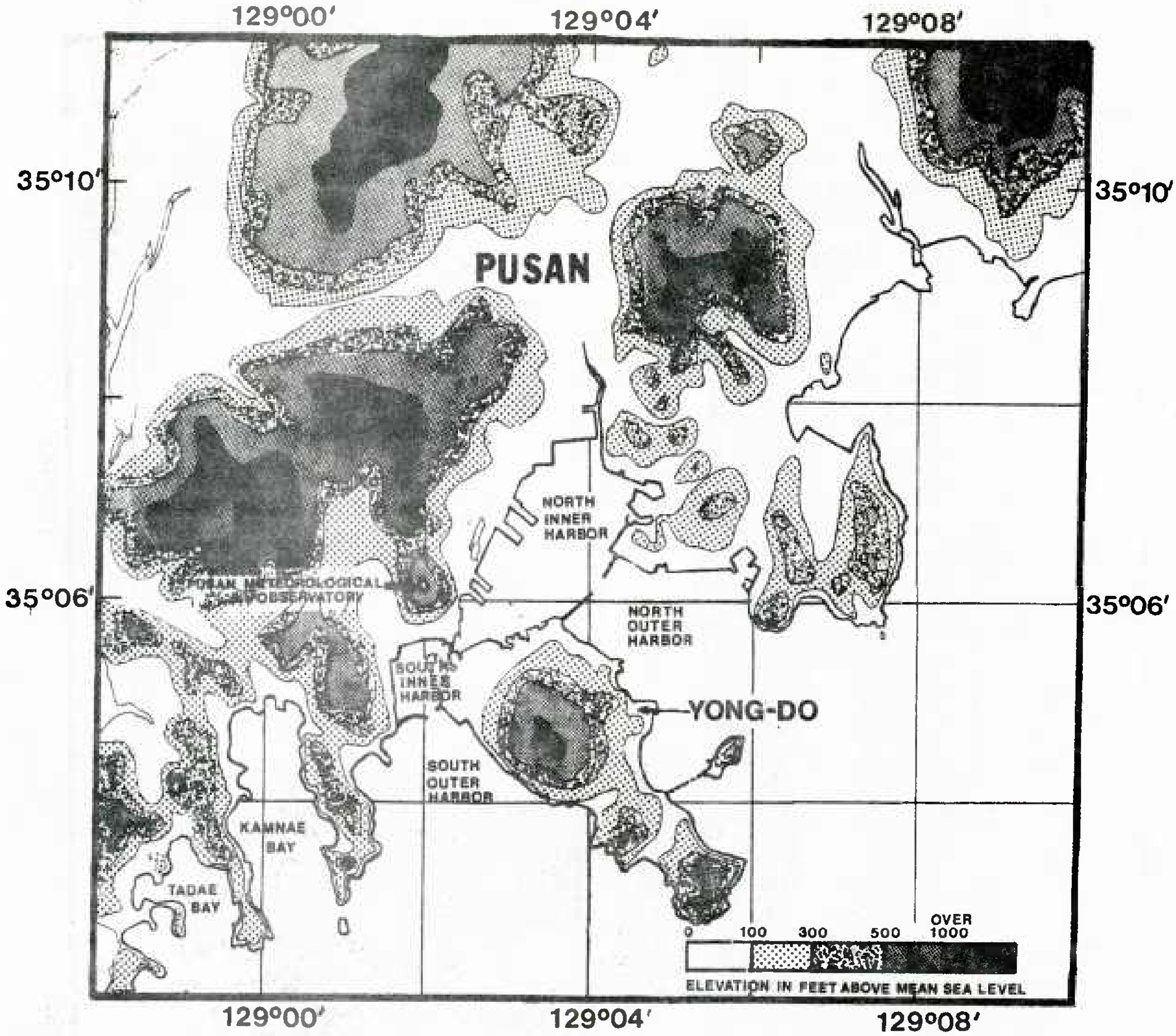


Figure 23. Pusan Harbor and surrounding topography.

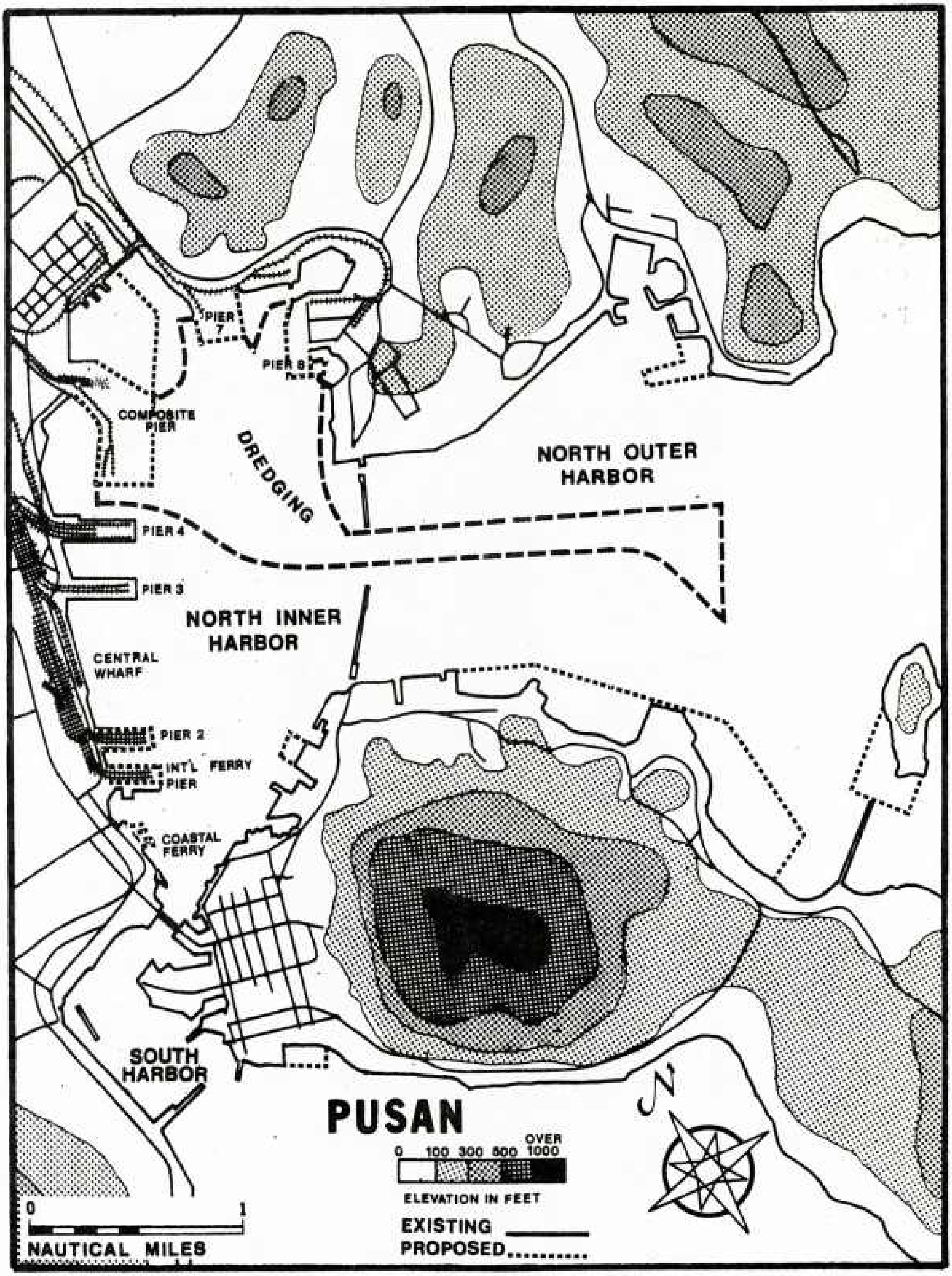


Figure 24. Existing and proposed Pusan Harbor facilities.

## 8.4 HARBOR FACILITIES

The Pusan Inner Harbor consists of 4 major piers, 2 quays, and 6 deep-draft anchorages. Cranes, drydocks and repair facilities are all available. For a detailed description of harbor facilities available in Pusan, refer to CINCPACFLT Port Directory, Volume V, section B1 or the Far East Port Directory, MSTSFE Instruction 3170.4A, section II-26.

# 9. TROPICAL CYCLONES AFFECTING PUSAN

## 9.1 CLIMATOLOGY FOR PUSAN AND CHINHAE HARBORS

The climatology of tropical cyclones for Pusan and Chinhae Harbors will be combined since the two harbors are less than 20 n mi apart. The midpoint of a line between the two harbors was used for the following climatology. For purposes of this study, any tropical cyclone that entered a 180 n mi circle radially outward from this midpoint was considered to be a threat to Pusan/Chinhae Harbor and designated as a "threat" tropical cyclone.

The "threat" period for Pusan/Chinhae extends from the end of June through the middle of October. This is indicated in Figure 25 which depicts the monthly summary by 5-day periods of tropical cyclone occurrences based on data for June-October, 1947-1973. During this 27-year period, 57 tropical cyclones "threatened" Pusan/Chinhae, an average of approximately two tropical cyclones per year. August is the peak "threat" period (35%) followed by September and July. Only 16% of the "threat" tropical cyclones occurred during June and October. Figure 25 also indicates that 80% of the "threat" tropical cyclones are "recurvers" (had a northeasterly component of motion).

Figure 26 displays the "threat" tropical cyclones according to the compass octant from which they approached Pusan/Chinhae. The circled numbers indicate the total that entered from an individual octant. The adjacent numbers express this as a percentage. It is evident that 81% of the "threat" tropical cyclones entered the threat area from a sector extending from SW to SE.

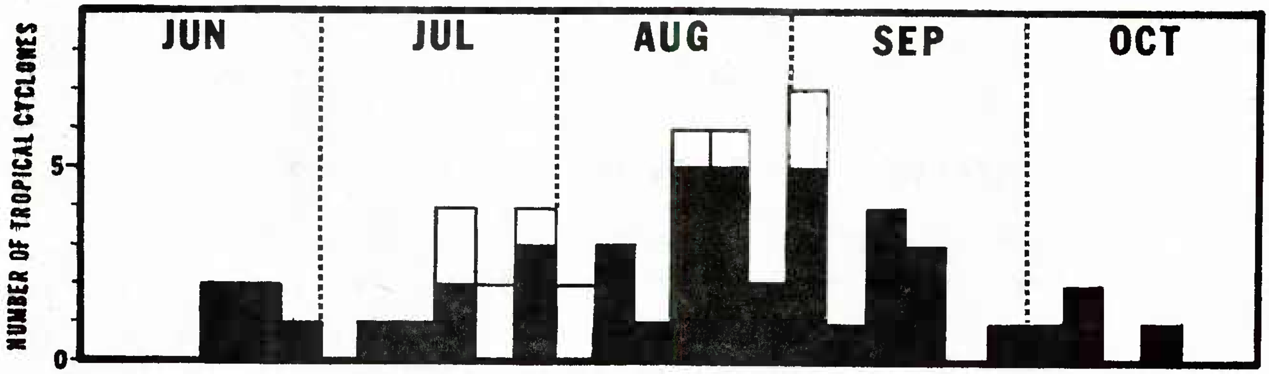


Figure 25. Frequency distribution of the number of tropical cyclones that passed within 180 n mi of Pusan/Chinhae. Subtotals are based on 5-day periods for tropical cyclones that occurred during 1947-1973. Shaded area indicates the number of recurving tropical cyclones per 5-day period.

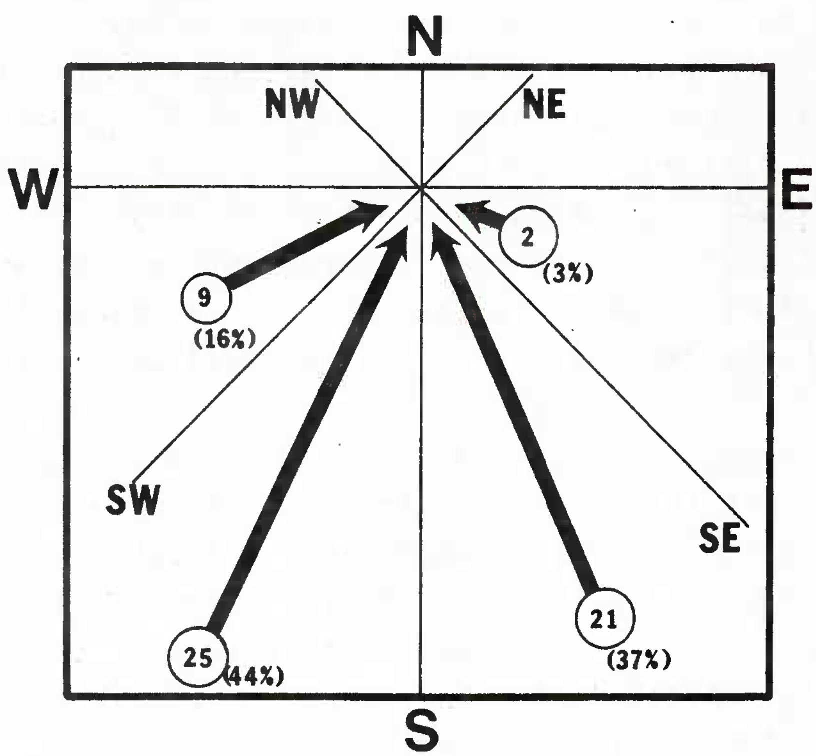


Figure 26. Direction of approach to Pusan/Chinhae of tropical cyclones that passed within 180 n mi of Pusan/ Chinhae. Circled numbers indicate the total number that approached from each octant. This is expressed as a percentage in parenthesis.

Table 6 indicates that out of the 57 "threat" tropical cyclones during June-October, 1947-1973, 54% passed to the west and 46% passed to the east of the midpoint of a line between Pusan and Chinhae. Therefore, the chances of having a "threat" tropical cyclone pass to the west of this midpoint is somewhat greater than passage to the east of this midpoint.

Table 6. "Threat" tropical cyclone passage relative to the midpoint of a line between Pusan and Chinhae.

| Month | Jun | Jul | Aug | Sep | Oct | Total | % |
|---|---|---|---|---|---|---|---|
| Passed east of midpoint | 4 | 3 | 10 | 6 | 3 | 26 | 46% |
| Passed west of midpoint | 1 | 9 | 10 | 10 | 1 | 31 | 54% |

Over 40% of the "threat" tropical cyclones affecting Pusan/Chinhae either travel over or dissipate on the southwestern tip of Japan. It was noted previously (section 5.1) that as a result of the tropical cyclone's interaction with land, the maximum wind intensity decreases. During August (including the end of July - beginning of September) the mean sea-surface temperatures (SST) in the Sea of Japan and Yellow Sea are favorable for tropical cyclone reintensification when it leaves the southwestern tip of Japan (Robinson and Bauer, 1971).

Figures 27-31 are based on the same analysis as discussed in section 5.1. The approach times (dashed lines) are based on the average speed of movements of tropical cyclones that affect Pusan/Chinhae and are presented as Table 7. The solid lines represent the "percent threat" for any storm location. For example, in Figure 27, a storm located at 30N and 130E has a 40% probability of passing within 180 n mi of Pusan/Chinhae and it could reach Pusan/Chinhae in less than one day.

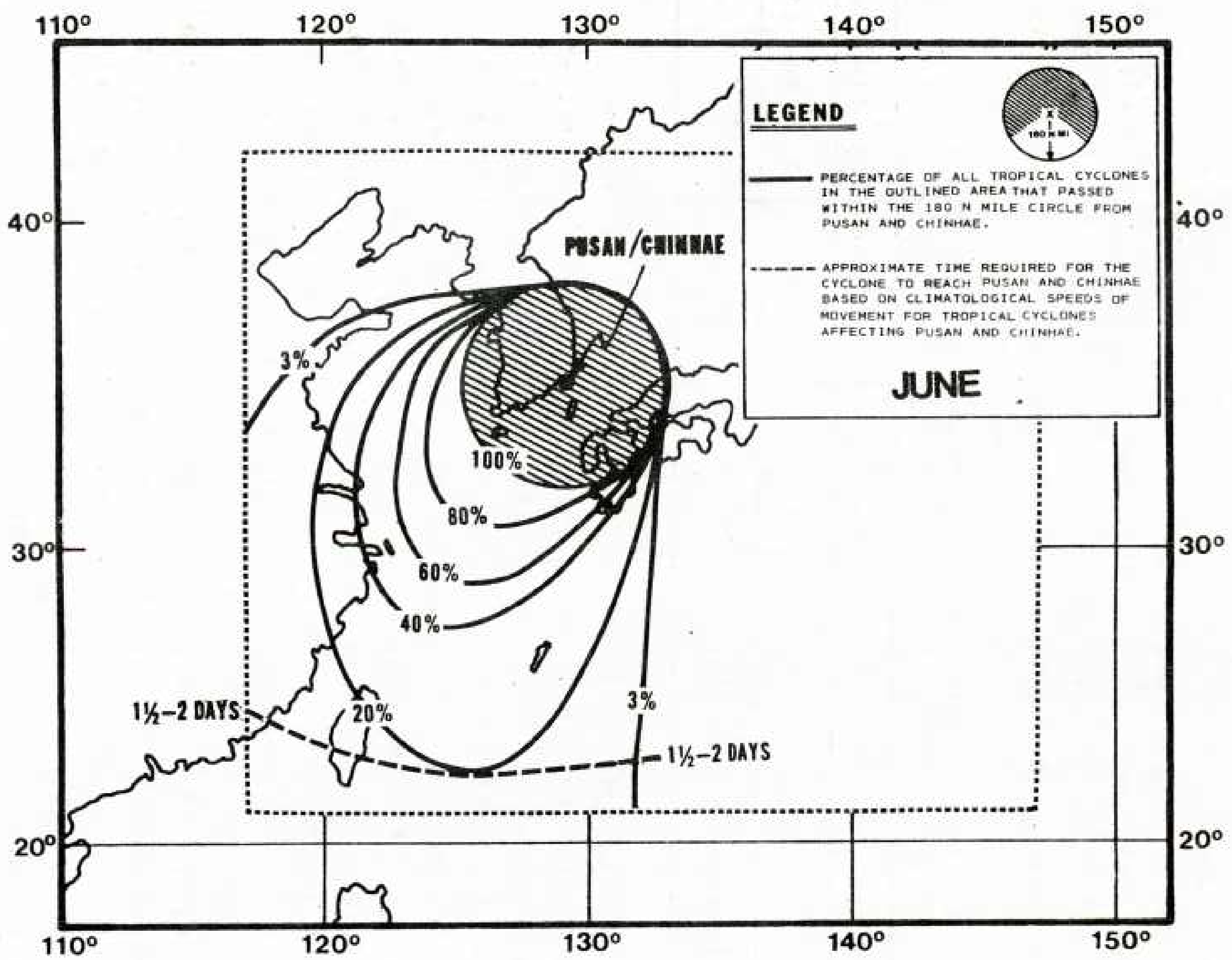


Figure 27. Percentage of tropical cyclones that passed within 180 n mi of the midpoint of a line between Pusan and Chinhae Harbors for the month of June (based on June-October data from 1947-1973).

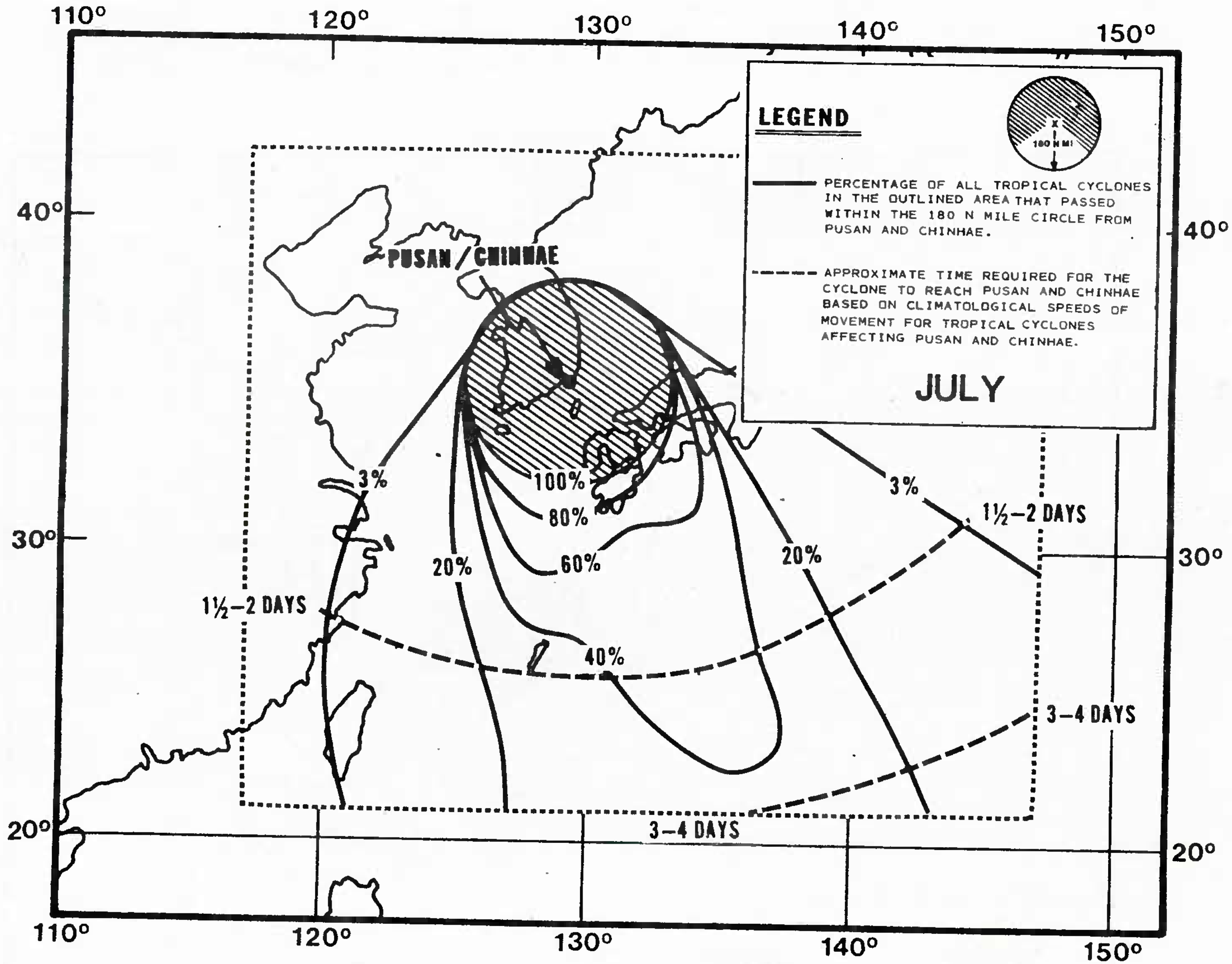


Figure 28. Percentage of tropical cyclones that passed within 180 n mi of the midpoint of a line between Pusan and Chinhae Harbors for the month of July (based on June-October data from 1947-1973).

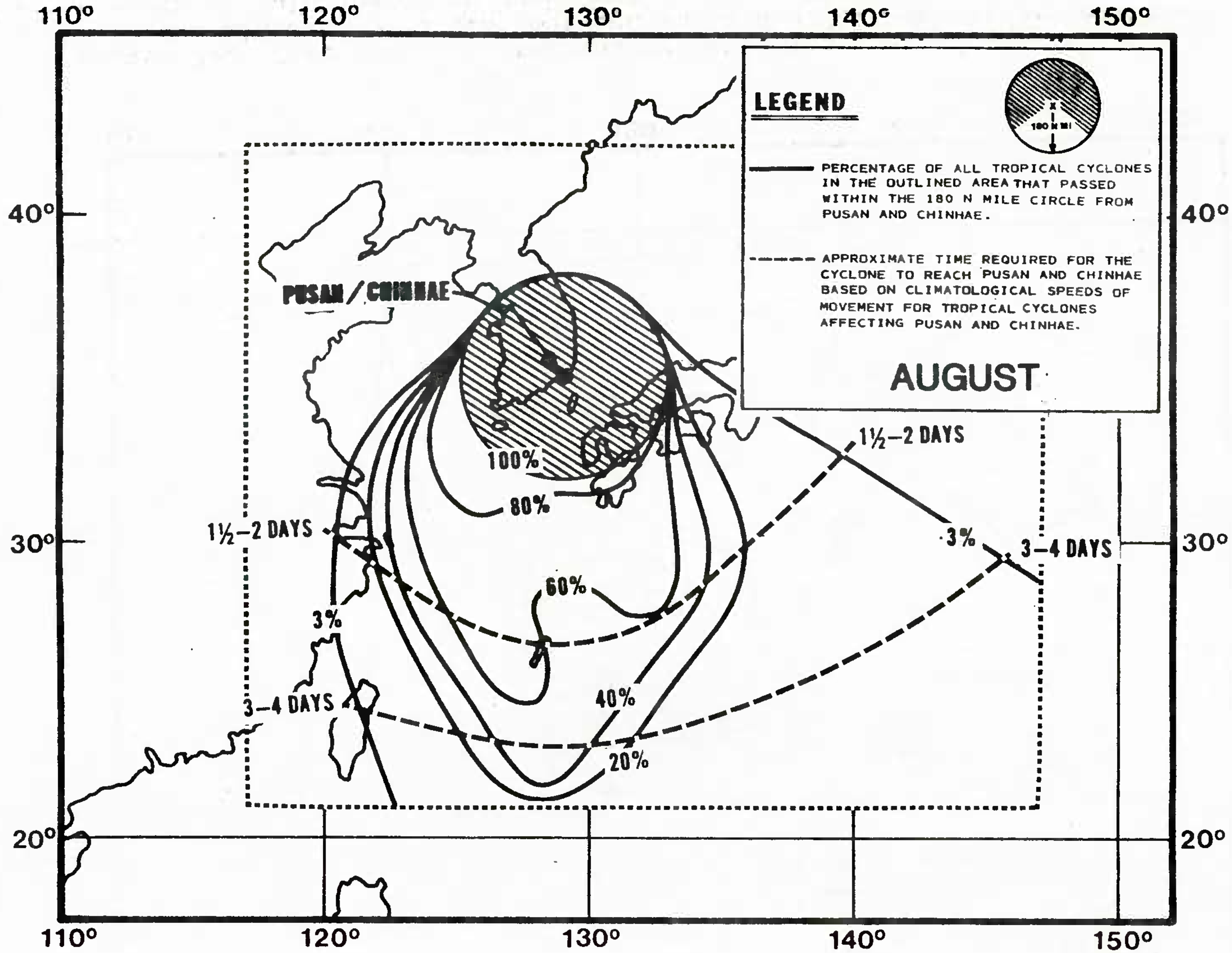


Figure 29. Percentage of tropical cyclones that passed within 180 n mi of the midpoint of a line between Pusan and Chinhae Harbors for the month of August (based on June-October data from 1947-1973).

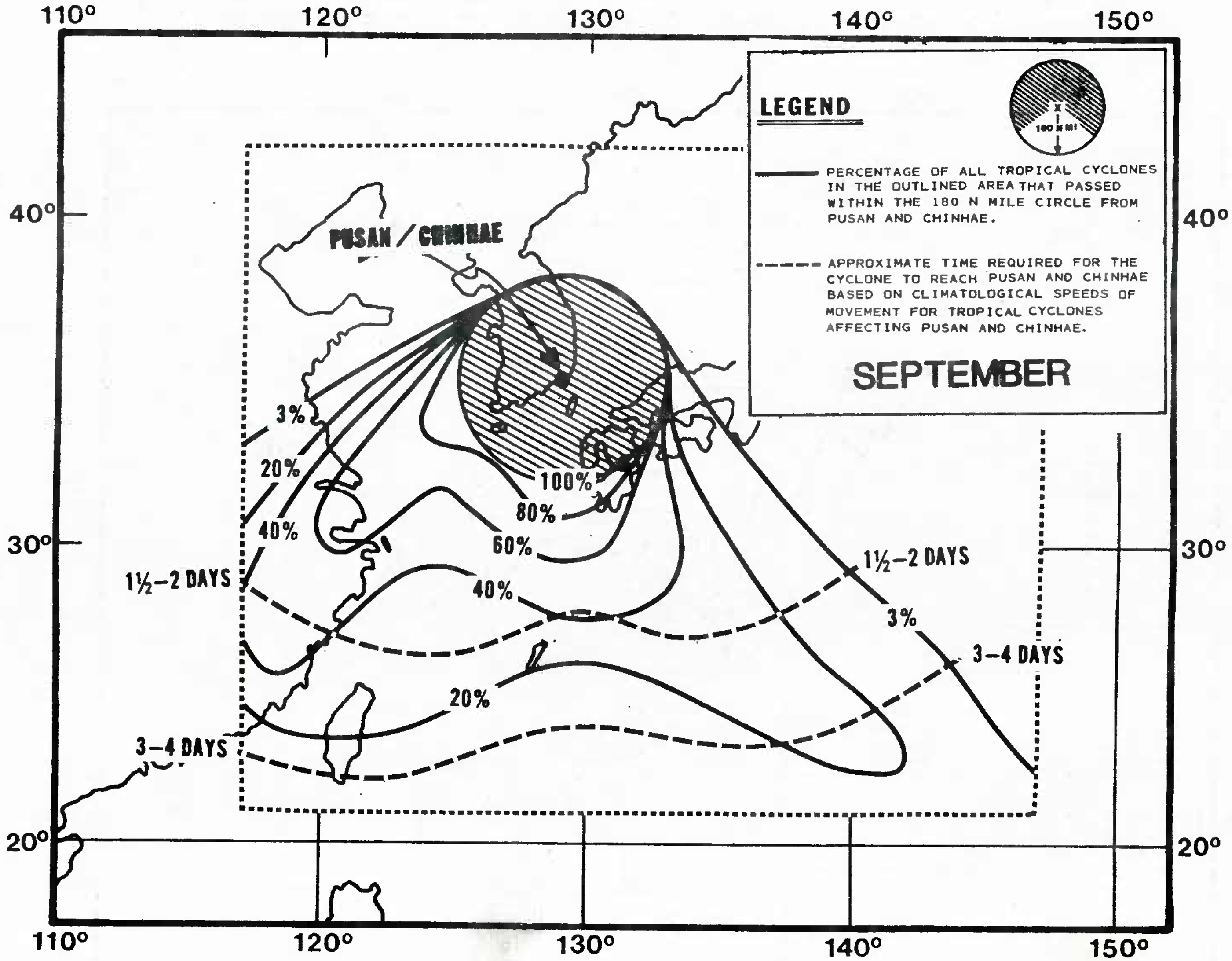


Figure 30. Percentage of tropical cyclones that passed within 180 n mi of the midpoint of a line between Pusan and Chinhae Harbors for the month of September (based on June-October data from 1947-1973).

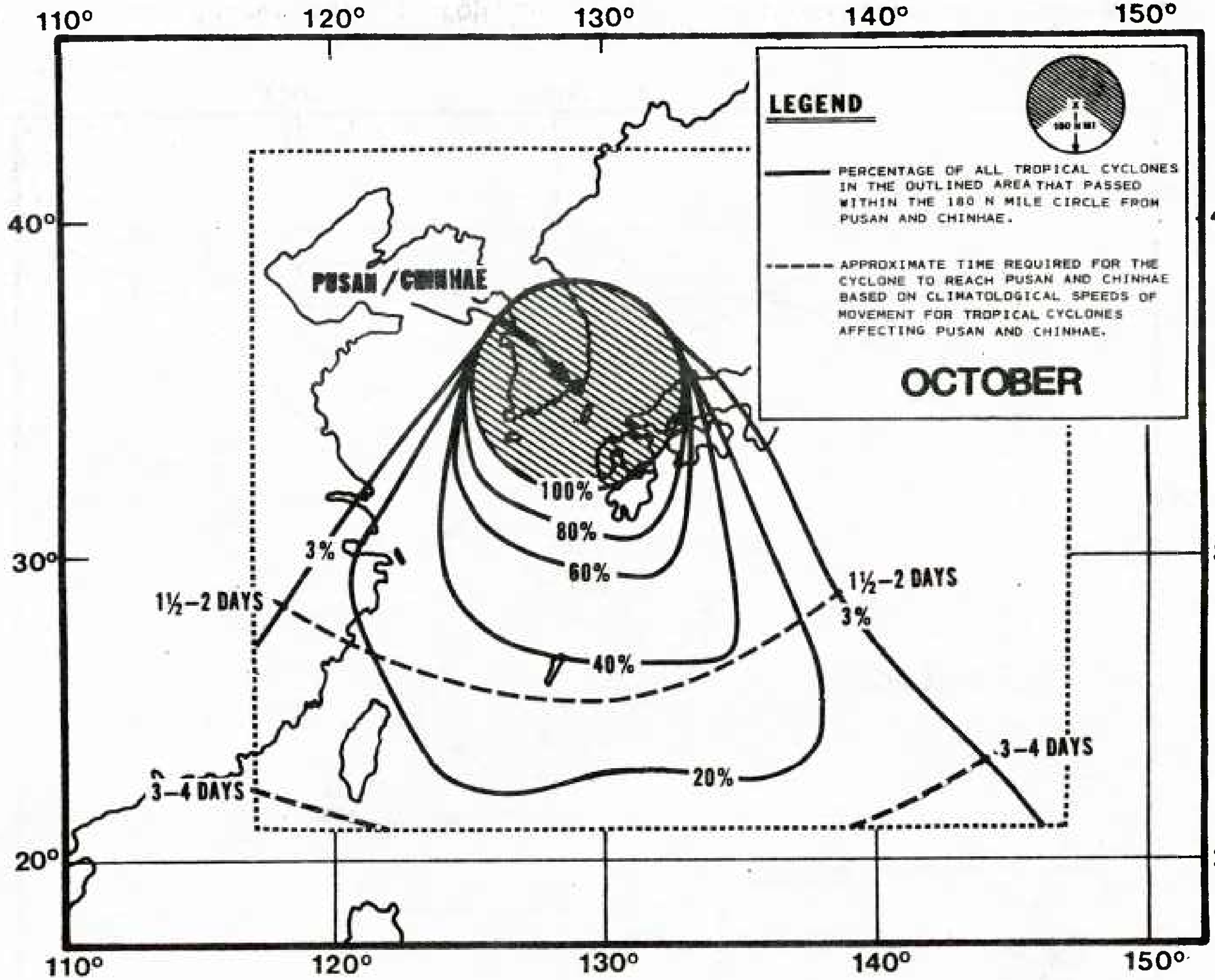


Figure 31. Percentage of tropical cyclones that passed within 180 n mi of the midpoint of a line between Pusan and Chinhae Harbors for the month of October (based on June-October data from 1947-1973).

Table 7. Listing of June-October average climatological speeds of tropical cyclones affecting Pusan/Chinhae by 5-degree latitude bands.

| Latitude Band (°N) | Average Forward Speed of Movement(kt) | | | | | Average of the 5 Months (kt) |
|---|---|---|---|---|---|---|
| | Jun | Jul | Aug | Sep | Oct | |
| 35-40 N | 28 | 20 | 21 | 26 | 16 | 22.2 |
| 30-35 | 24 | 13 | 14 | 19 | 15 | 17.0 |
| 25-30 | 17 | 11 | 9 | 13 | 14 | 12.8 |
| 20-25 | 12 | 11 | 9 | 11 | 13 | 11.2 |
| 15-20 | 9 | 10 | 10 | 11 | 12 | 10.8 |

Note the significant shift in direction from which "threat" tropical cyclones approach Pusan/Chinhae (Figures 27-31). In June, the "threat" is generally from the south-west, whereas in July it is from the southeast. During August the "threat" sector extends from south to southeast and, in September, the "threat" is from the southeast and southwest. During October the "threat" sector narrows again and is primarily from the south-southeast.

## 9.2 WIND AND TOPOGRAPHICAL EFFECTS

Based on topographical considerations, strong winds can be expected from the north-northeast, southeast and southwest of Pusan since little topographic protection is available from these directions (see Figure 23). The southerly winds would be associated with "threat" tropical cyclone passage to the west of Pusan while northerly winds would result from "threat" tropical cyclone passage east of Pusan.

To determine the extent to which "threat" tropical cyclones produced strong winds ($\geq$ 22 kt) or gale force winds ($\geq$ 34 kt) in Pusan, the wind observations from the Pusan Meteorological Observatory (35°06'N, 129°02'E; see Figure 23) were analyzed from June-October, 1948-1973.

The proximity of the Observatory to the harbor makes the winds recorded at the station representative of the wind conditions experienced in the harbor for all directions except the southeast. Winds from this direction will be less at the Observatory than in the harbor due to the blocking action of Yong-Do Island.

Table 8 groups the 55 tropical cyclones that "threatened" Pusan during this 26 year period according to the wind intensity that they produced in Pusan. Of the 55 "threat" tropical cyclones, 67% resulted in strong winds ($\geq$ 22 kt) and 29% resulted in gale force winds ($\geq$ 34 kt).

Table 8. Extent to which "threat" tropical cyclones affected Pusan during June-October, 1948-1973.

| | | |
|---|---|---|
| Number of tropical cyclones that "threatened" Pusan | 55 | % |
| Number of "threat" tropical cyclones resulting in strong ($\geq$ 22 kt) winds in Pusan | 37 | 67% |
| Number of "threat" tropical cyclones resulting in gale force ($\geq$ 34 kt) winds in Pusan | 16 | 29% |

Figures 32-36 depict the tracks of the "threat" tropical cyclones during June-October, 1948-1973. Those resulting in gale force winds at Pusan are indicated by a dashed line. "Threat" tropical cyclone tracks resulting in winds less than 34 kt are depicted by a solid line. From analyses of the "threat" tropical cyclone tracks (Figures 32-36), the following is apparent:

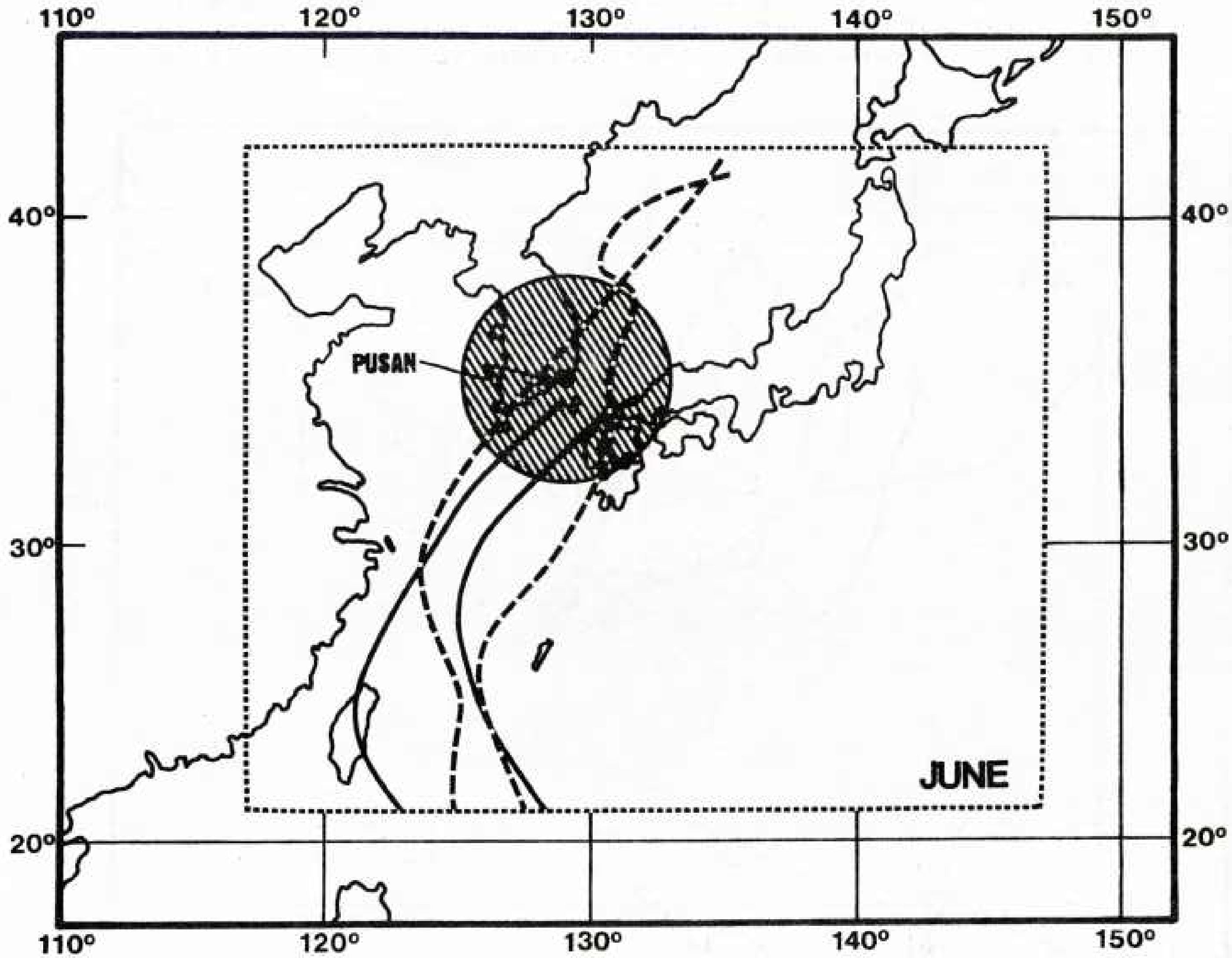


Figure 32. Tracks of tropical cyclones approaching within 180 n mi of Pusan during the 26-year period, 1948-1973 for June. Dashed line indicates tracks of tropical cyclones that produced winds $\geq$ 34 kt at Pusan. Solid line indicates tropical cyclones passing within 180 n mi of Pusan but not producing winds $\geq$ 34 kt at Pusan.

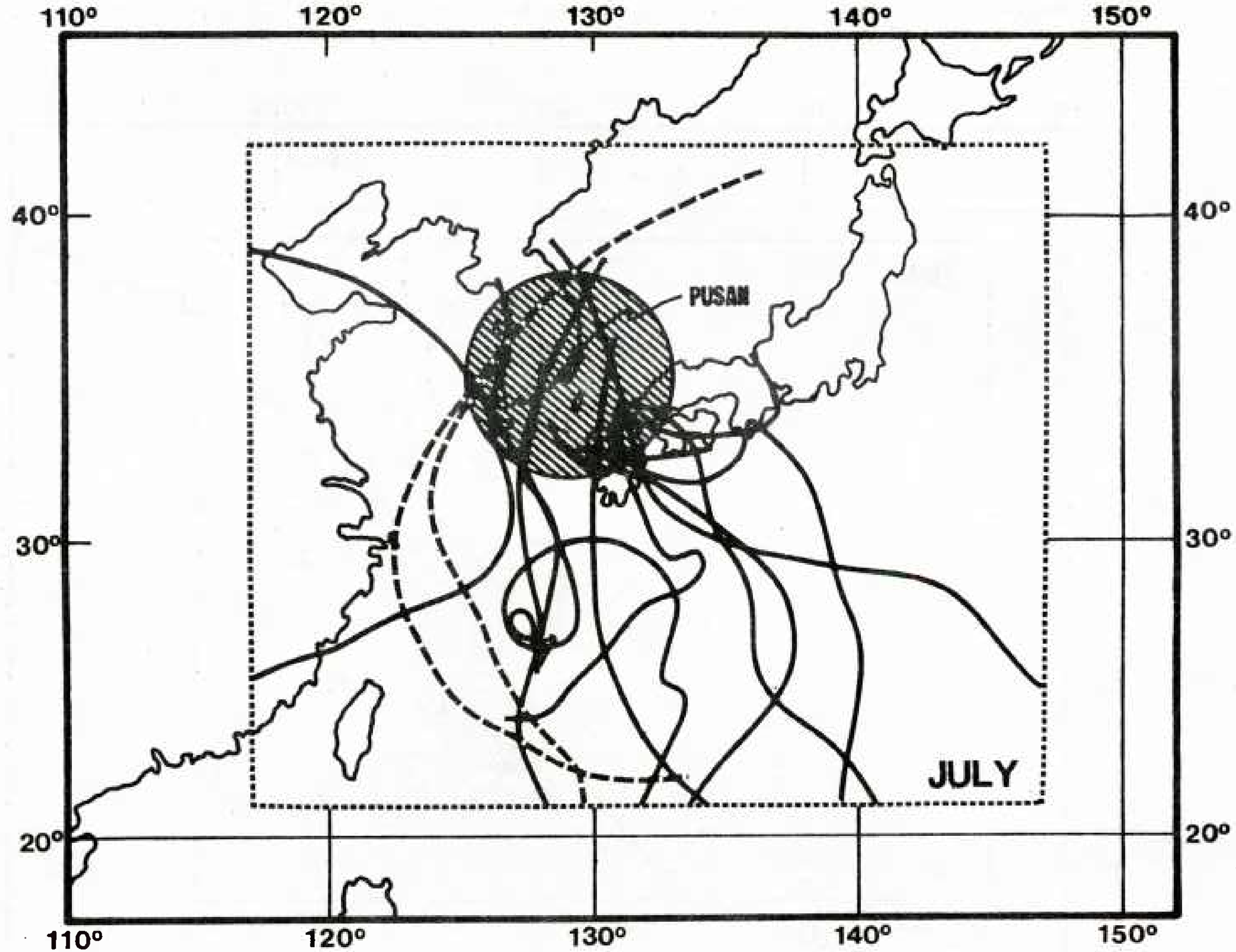


Figure 33. Tracks of tropical cyclones approaching within 180 n mi of Pusan during the 26-year period, 1948-1973 for July. Dashed line indicates tracks of tropical cyclones that produced winds $\geq$ 34 kt at Pusan. Solid line indicates tropical cyclones passing within 180 n mi of Pusan but not producing winds $\geq$ 34 kt at Pusan.

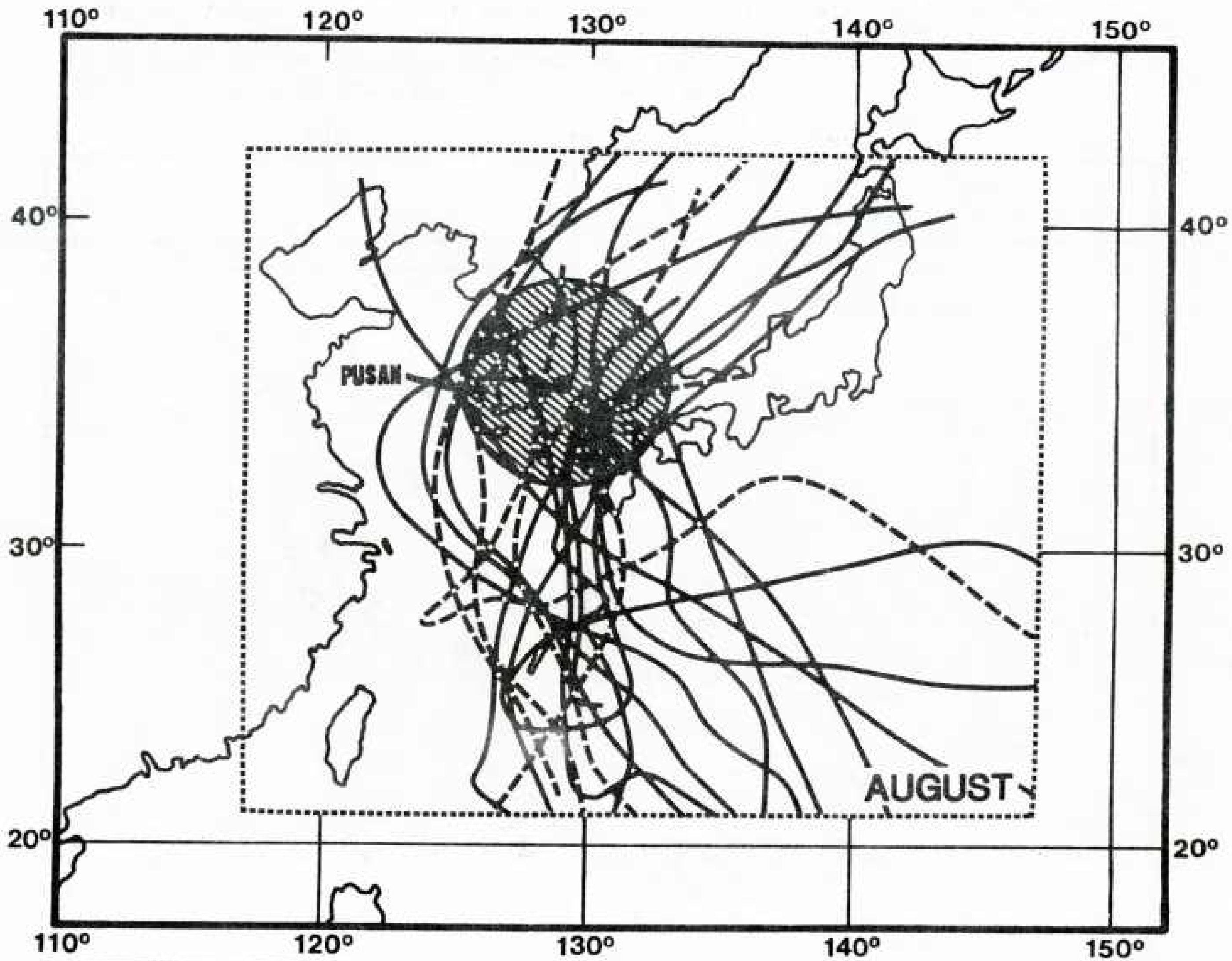


Figure 34. Tracks of tropical cyclones approaching within 180 n mi of Pusan during the 26-year period, 1948-1973 for August. Dashed line indicates tracks of tropical cyclones that produced winds $\geq$ 34 kt at Pusan. Solid line indicates tropical cyclones passing within 180 n mi of Pusan but not producing winds $\geq$ 34 kt at Pusan.

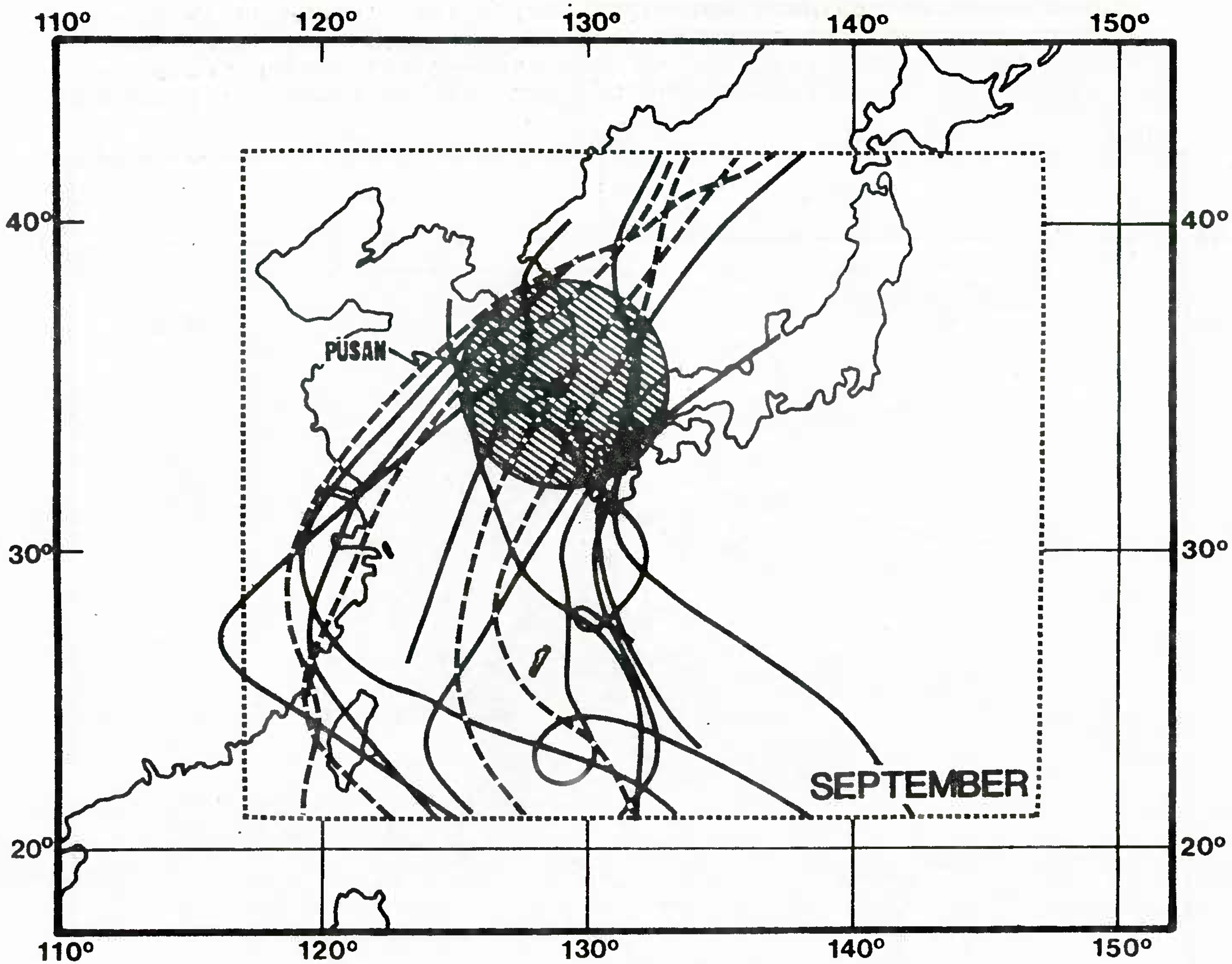


Figure 35. Tracks of tropical cyclones approaching within 180 n mi of Pusan during the 26-year period, 1948-1973 for September. Dashed line indicates tracks of tropical cyclones that produced winds $\geq$ 34 kt at Pusan. Solid line indicates tropical cyclones passing within 180 n mi of Pusan but not producing winds $\geq$ 34 kt at Pusan.

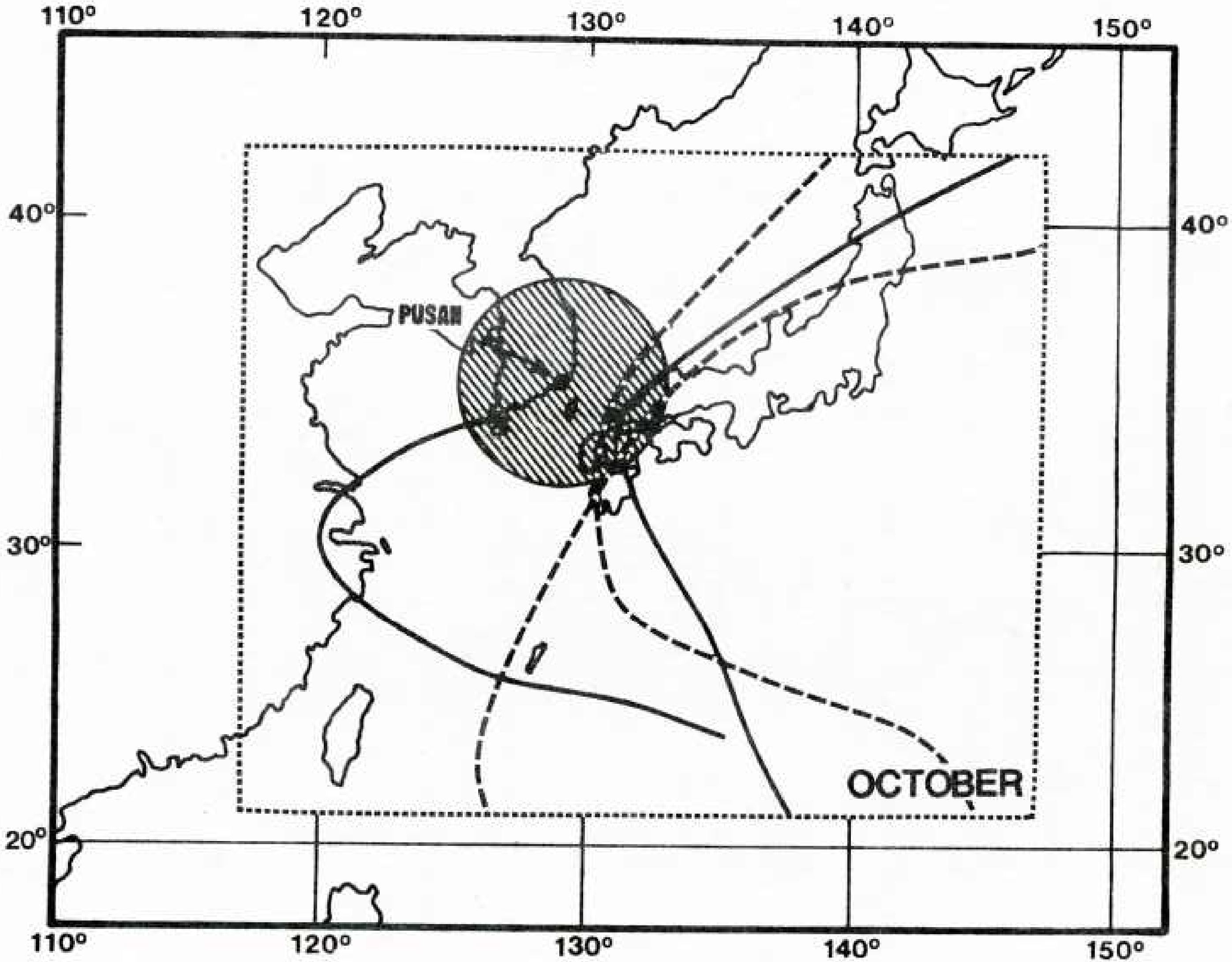


Figure 36. Tracks of tropical cyclones approaching within 180 n mi of Pusan during the 26-year period, 1948-1973 for October. Dashed line indicates tracks of tropical cyclones that produced winds $\geq$ 34 kt at Pusan. Solid line indicates tropical cyclones passing within 180 n mi of Pusan but not producing winds $\geq$ 34 kt at Pusan.

(1) Gale force winds resulting from a "threat" tropical cyclone occurred in each month during June-October

(2) That the "threat tropical cyclones producing gale force winds at Pusan are more likely to pass west of Pusan (62%) than to the east (38%)

Figure 37 shows the positions of "threat" tropical cyclone centers when strong winds ($\geq$ 22 kt) were first and last recorded at Pusan. It is apparent that "threat" tropical cyclones in general, over 300 n mi away, may produce winds $\geq$ 22 kt in Pusan. Also evident from Figures 37 is the fact that passage over Japan acts to reduce the effects associated with the threat tropical cyclones.

Figure 38 shows tropical cyclone center positions when gale force ($\geq$ 34 kt) winds were first and last recorded at Pusan. It can be seen that winds $\geq$ 34 kt result in Pusan more from tropical cyclones passing to the west than to the east of Pusan. It is felt that the most severe threat is associated with tropical cyclone passage just west of Pusan since the resulting southerly winds (especially from the southeast) are virtually unblocked before they reach the harbor. The maximum sustained wind velocity recorded at Pusan during June-October, 1948-1973 was 70 kt in 1959. This wind resulted from Typhoon Sarah's passage just 10 n mi west of Pusan.

## 9.3 WAVE ACTION

The maximum wave heights that can be expected with typhoon strength winds ($\geq$ 64 kt) in Pusan's North Harbor are presented as Table 9.

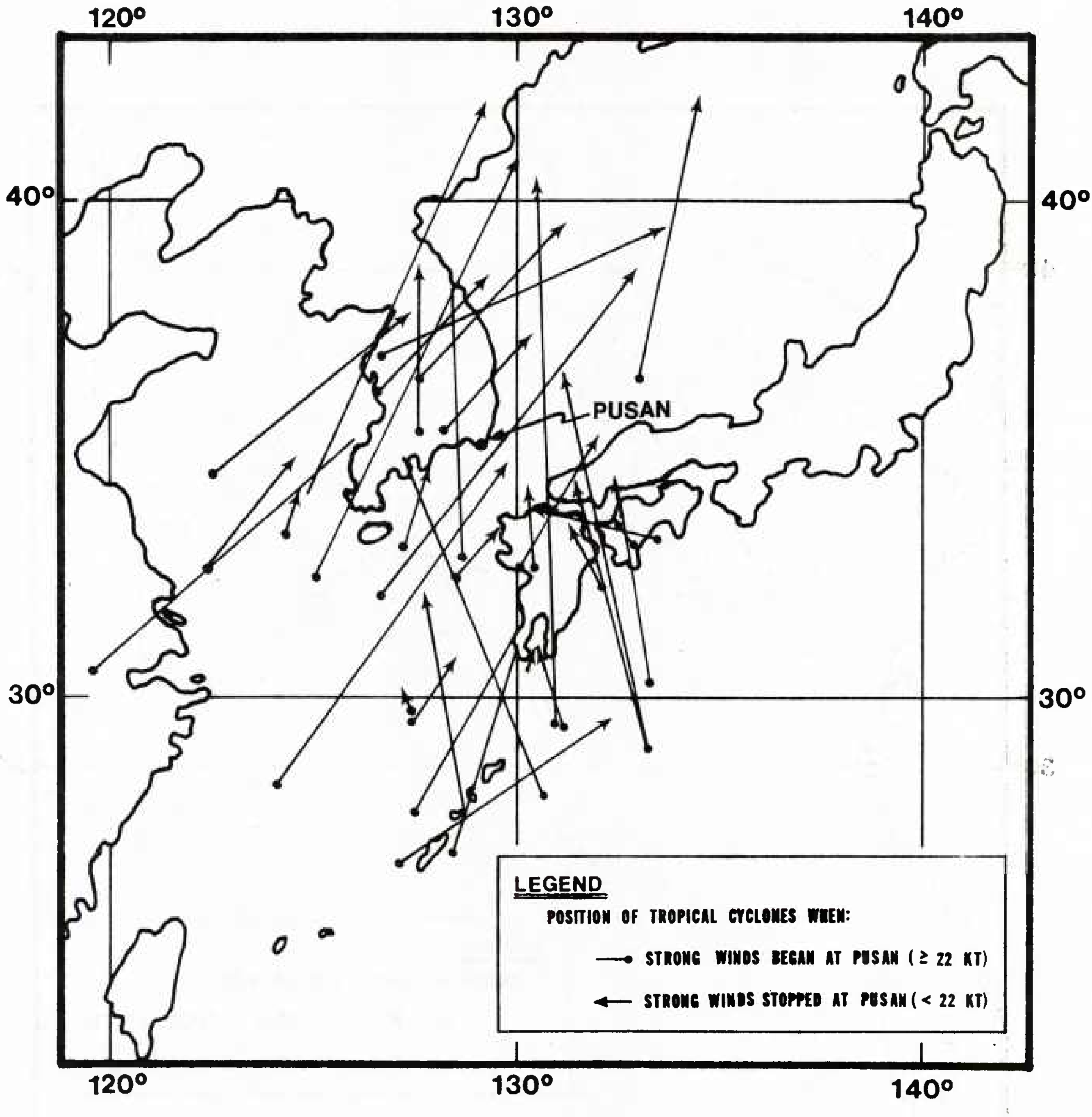


Figure 37. Positions of tropical cyclone centers when $\geq$ 22 kt winds first and last occurred at Pusan (based on June-October data from the years 1948-1973).

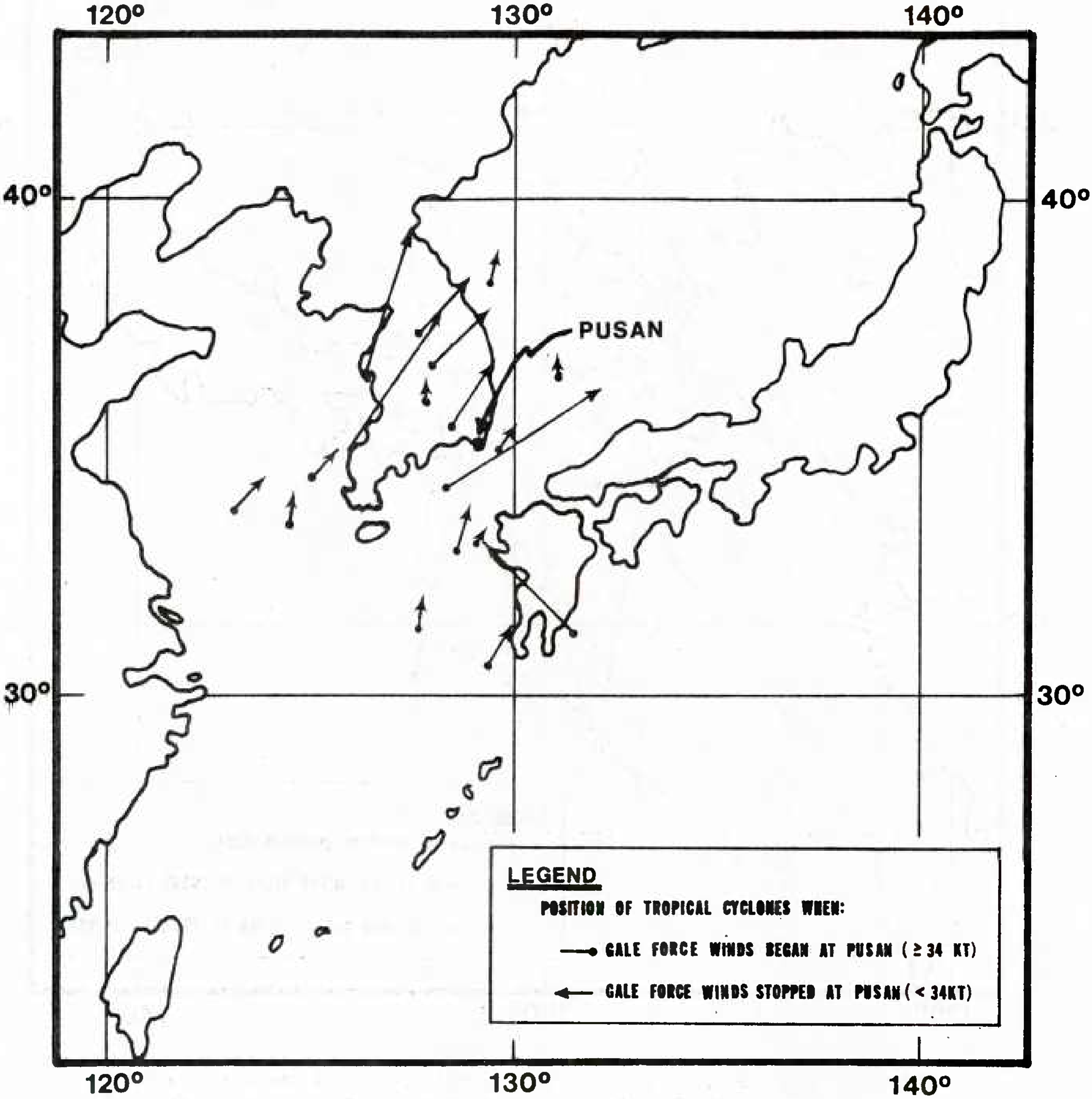


Figure 38. Positions of tropical cyclone centers when ≥ 34 kt winds first and last occurred at Pusan (based on June-October data from the years 1948-1973).

Table 9. Maximum wave heights that can be expected with typhoon strength winds ($\geq$ 64 kt) in North Outer and Inner Harbor (based on relationships extracted from U.S. Army Coastal Engineering Research Center, 1973).

| Location | North Outer Harbor | North Inner Harbor |
|---|---|---|
| Winds generally from the north (tropical cyclone passage east of Pusan) | 4 ft | 5 ft |
| Winds generally from the south (tropical cyclone passage west of Pusan) | 12 ft | 4 ft |

Wave action in the North Inner Harbor is minimal due to the short fetch. The North Outer Harbor presents a fetch of about 100 n mi for winds out of the southeast and therefore high wave action can be expected if winds are from this direction.

## 9.4 STORM SURGE AND TIDES

During periods of moderate to strong south to southeasterly winds (tropical cyclone passage west of Pusan), a surge effect is evident in the Inner Harbor. This is caused by wind stress on the water surface and the effects of atmospheric pressure reduction. When this surge effect coincides with high tide, an abnormal rise in water level occurs. The only damage reports available as a result of this phenomenon was associated with Typhoon Sarah (see Appendix E for a case study on this particular typhoon).

## 10. PREPARATION FOR HEAVY WEATHER AT PUSAN

### 10.1 TROPICAL CYCLONE WARNINGS

For general information about tropical cyclone warnings the reader is referred to section 6.1.

### 10.2 REMAINING IN PORT

Remaining in port is not the recommended course of action for the following reasons:

(1) The North Inner Harbor provides little protection from northerly winds (tropical cyclone passage east of Pusan). As a matter of fact, the valley to the north of the harbor will act to increase the wind velocity by its funneling action.

(2) The North Outer Harbor is exposed to southeasterly winds (tropical passage west of Pusan). In addition, the large fetch to the southeast can produce a sea state of up to 12 ft.

(3) A surge effect is present and when combined with a high tide may be dangerous.

### 10.3 EVASION

Evasion from Pusan Harbor is the preferred course of action when confronted with potential threatening conditions. The following evasion tactics are recommended:

1. Evasion to the Sea of Japan

This evasion route takes the ship to higher latitudes where the intensity of the tropical cyclone decreases markedly. The Sea of Japan provides ample maneuvering room to place the ship in the navigable or safe semicircle of the tropical cyclone. This evasion route also allows one to cross

to the Pacific Ocean from the Sea of Japan by means of Tsugaru Kaikyo between the southern tip of Hokkaido and the northern tip of Honshu.

It must be kept in mind when considering this tactic that more than likely the tropical cyclone will overtake the ship since the speed of movement of the tropical cyclone once it enters the Sea of Japan often is in excess of 30 kt. However, at the same time the intensity of the tropical cyclone decreases as it reaches the more northerly latitudes and the effects of the associated wind and sea will be much less intense than if the tropical cyclone is met at lower latitudes.

2. Evasion to Chinhae Bay - north of Koje Do (see Figure 22)

This is the evasion tactic used by the larger ROK Navy ships and is recommended if a need exists to remain in Korean waters. Chinhae Bay is a large landlocked bay formed by the northwest side of Koje Do and the mainland. The bay is entered from the east through the deep passage on either side of Chan Do (see Figure 22). The bottom of the bay is predominantly mud and shell and provides a good anchor holding action. Protection from strong winds is available in the bay for winds from all directions.

The only reports of damage available from ships in Chinhae Bay during a typhoon were associated with Typhoon Sarah in 1959. This typhoon passed approximately 10 n mi to the west of Pusan with central winds in excess of 90 kt. Several vessels ran aground in Chinhae Bay since they were not properly anchored. The damage to Pusan Harbor was much more severe.

3. Other evasion routes at sea may be developed by the use of the FWC/JTWC warnings, Appendix A (the mean tropical cyclone tracks, track limits, and average speed of movements for the months June-October) and Figures 39-43. The area enclosed by the threat axis depicted in Figures 39-43 represents a 30% or greater probability of being threatened by a tropical cyclone. Note how the orientation of the threat axis shifts from month to month.

To correctly assess the threat posed by an approaching tropical cyclone, the following timetable incorporating Figures 39-43 has been constructed for this purpose.

I. An existing tropical cyclone moves into or development takes place in area A with forecast movement toward Korea.

   a. Decide whether evasion is to be at sea or to Chinhae Bay.

   b. Review material condition of ship (destroyers should especially consider fuel). A sortie may be desirable 2-4 days hence.

   c. Reconsider any maintenance that would render the ship incapable of getting underway within 48 hours.

II. Tropical cyclone enters area B moving toward Pusan/Chinhae.

   a. All ships begin planning course of action to be taken if sortie should be ordered.

   b. Reconsider any maintenance that would render the ship incapable of getting underway within 24 hours.

III. Tropical cyclone enters area C moving toward Pusan/Chinhae.

   a. Execute sortie plans made in previous steps.

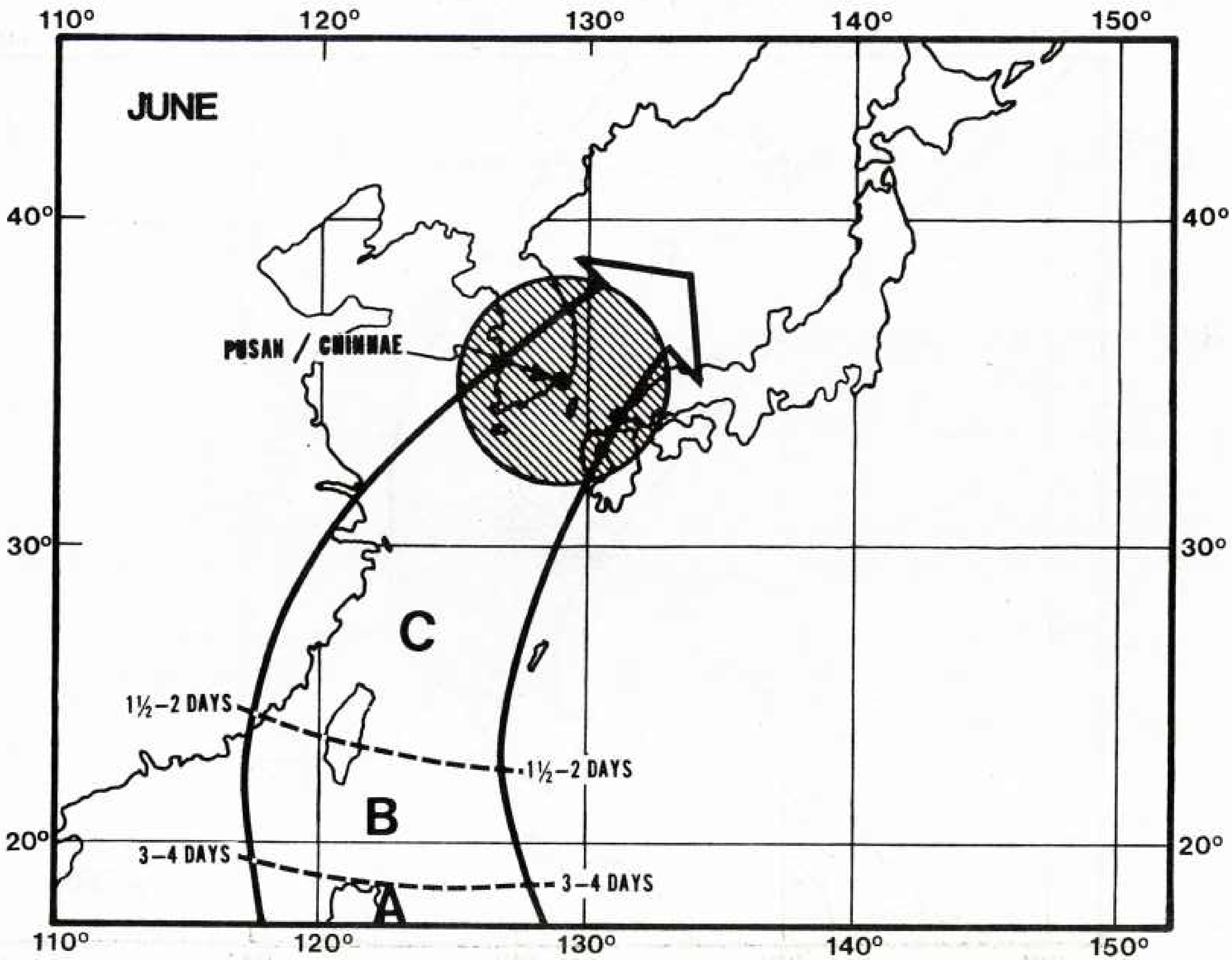


Figure 39. Tropical cyclone threat axis for the month of June.

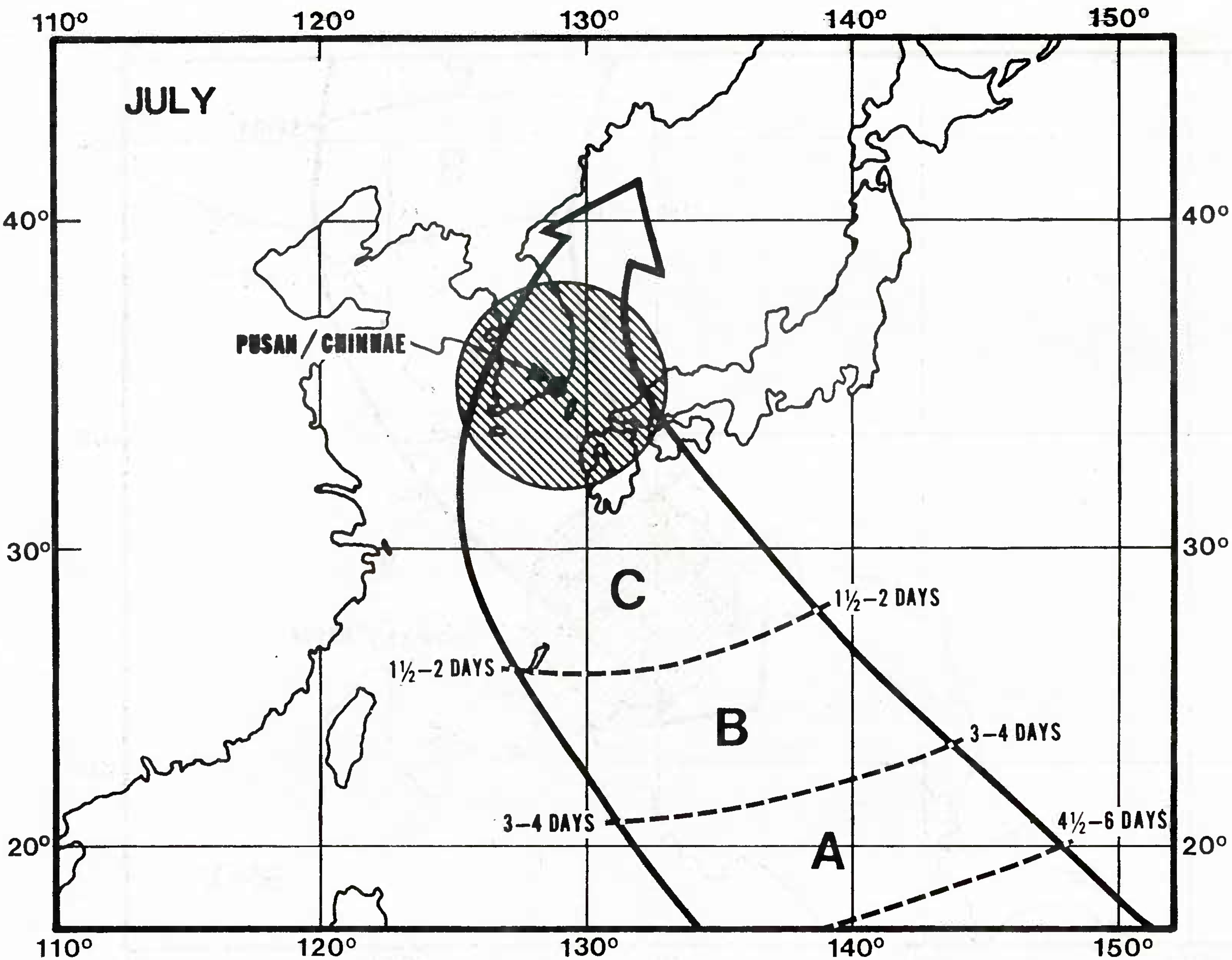


Figure 40. Tropical cyclone threat axis for the month of July.

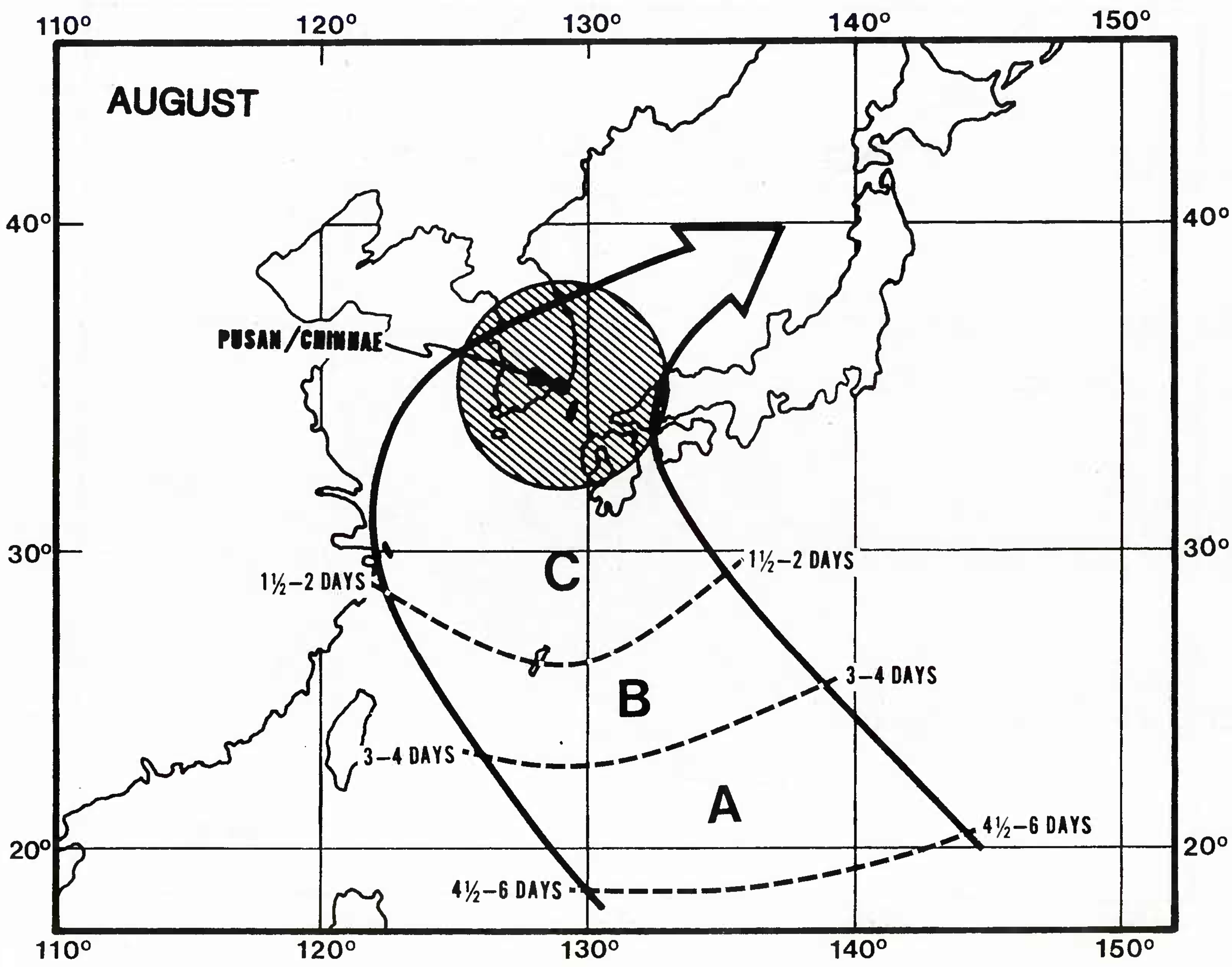


Figure 41. Tropical cyclone threat axis for the month of August.

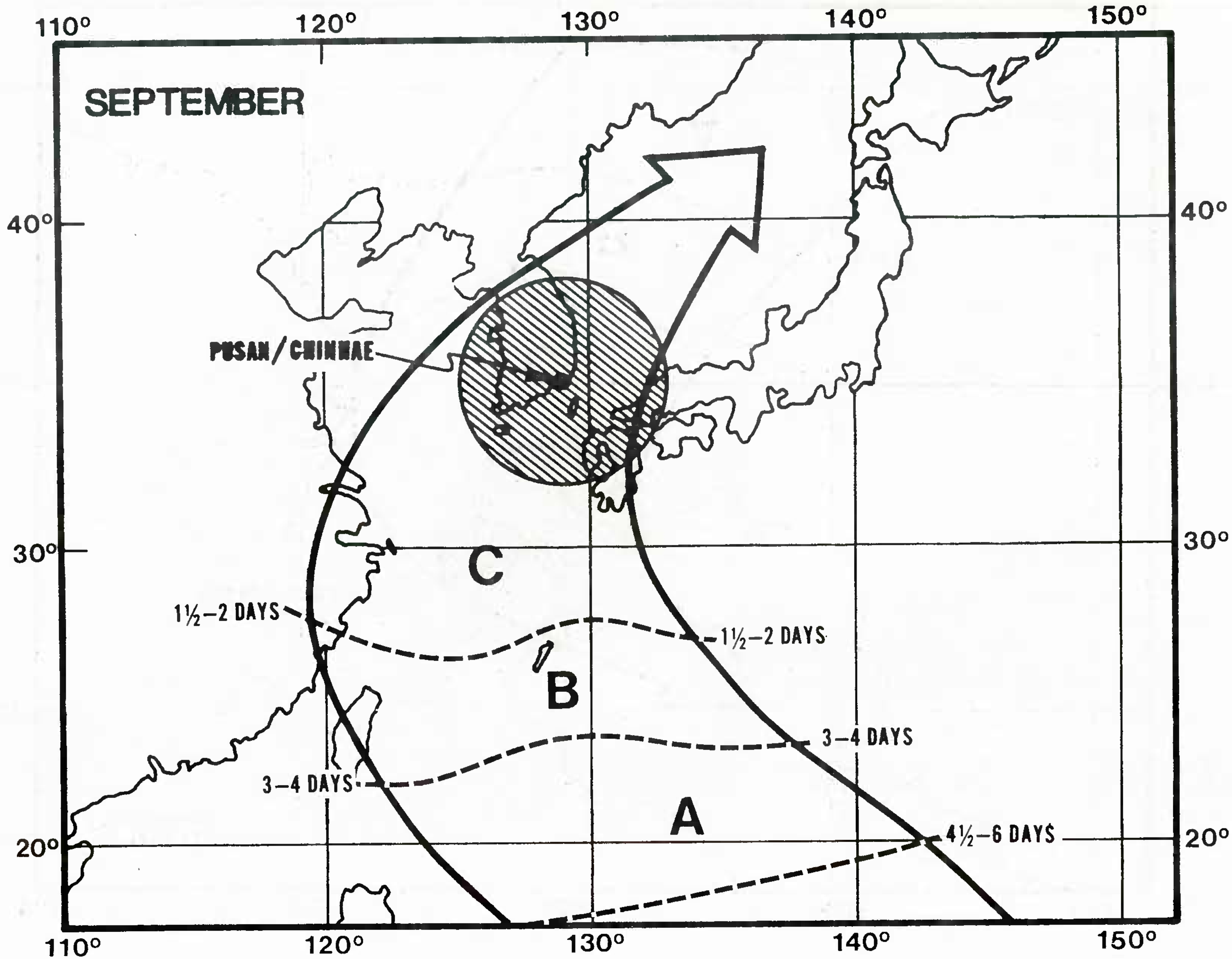


Figure 42. Tropical cyclone threat axis for the month of September.

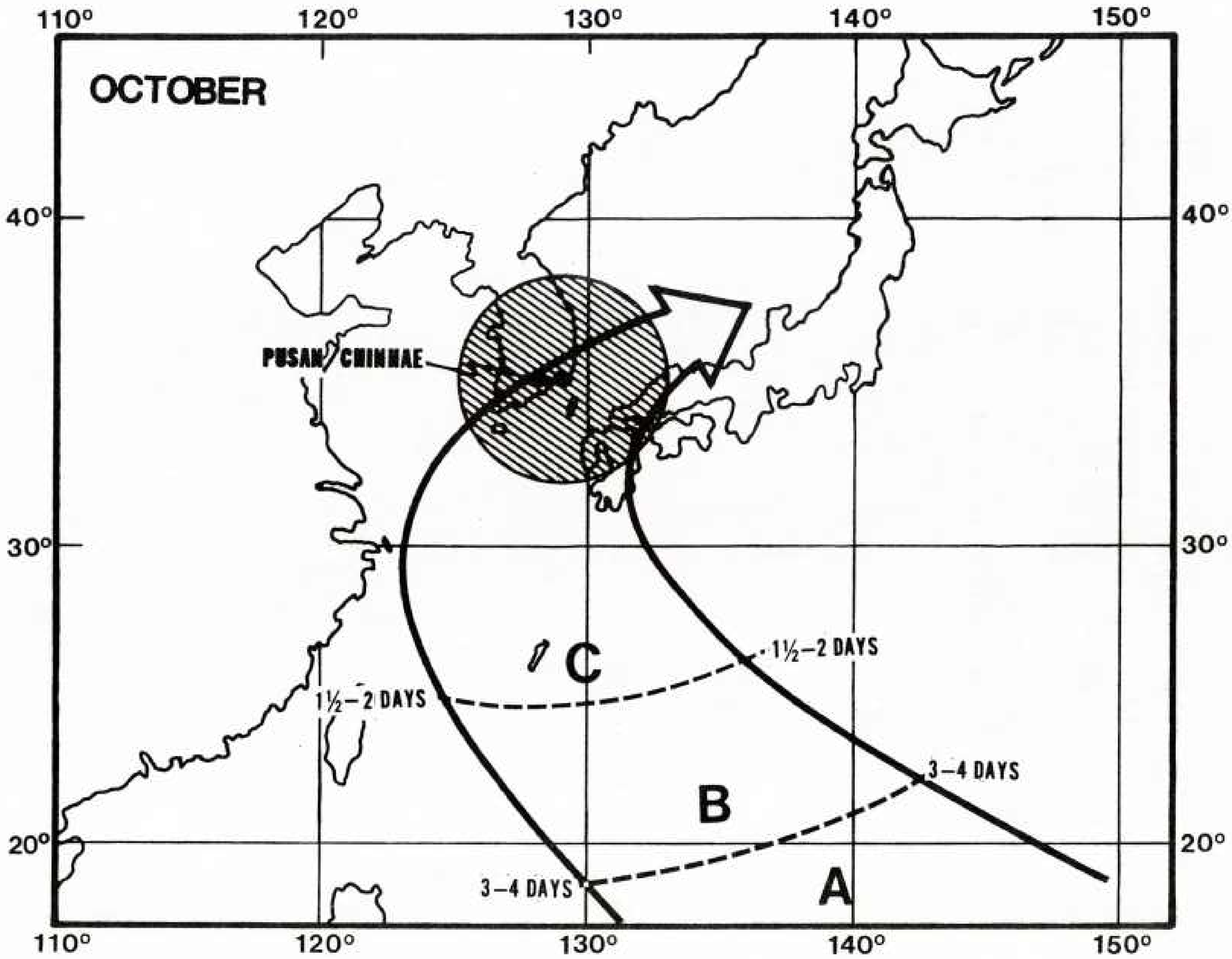


Figure 43. Tropical cyclone threat axis for the month of October.

## 11. CONCLUSIONS FOR PUSAN

It is the recommendation of this study that all U.S. Navy ships capable of taking action sortie from Pusan when threatening typhoon conditions exist.

The preferred evasion technique is to evade the typhoon in the Sea of Japan or, if need exists to remain in Korean waters, to seek shelter in Chinhae Bay.

# 12. CHINHAE

## 12.1 LOCATION

Chinhae Harbor, located at 35°08'N, 128°41'E on the southeast coast of the Korean Peninsula, is the site of the Republic of Korea's (ROK) principal naval base (see Figure 22). Less than 20 n mi due east from Chinhae Harbor is the port of Pusan.

## 12.2 CHINHAE HARBOR

The harbor has four piers and four quays that are used by the Republic of Korea Navy (ROK Navy). The usual berth for visiting ships is a quay constructed of stone and concrete, designated as pier 2. Pier 2 has two distinct berths with a depth of 25 ft at mean low tide.

Within the harbor twenty-four mooring buoys (reserved for ROK Navy) and thirty-nine anchorages (all in five to six fathoms of water) are available. Anchorages Z-1 and Z-2 are normally assigned to U.S. Navy ships.

The tidal range in the harbor is 6-8 ft and tidal currents of 1-1/2 kt can be expected in the approach channel.

## 12.3 TOPOGRAPHY

Chinhae Harbor is well protected by hills on all sides except to the south and southeast where it faces the ocean (see Figures 22 and 44). However protection is provided to the south by the hills on Koje Do. Only to the southeast is there no protection from winds.

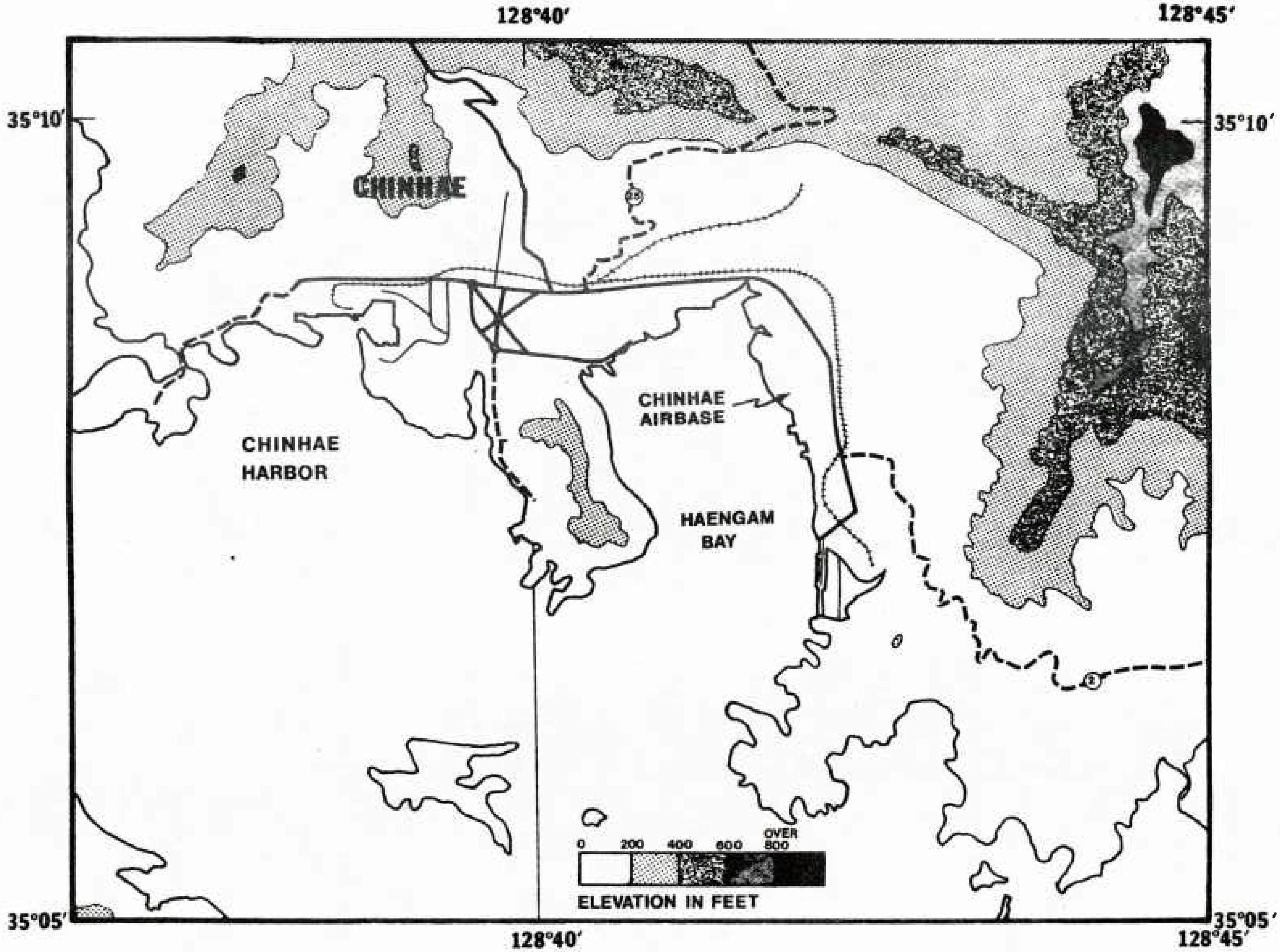


Figure 44. Chinhae Harbor and surrounding topography.

## 12.4 HARBOR FACILITIES

The ROKN shipyard has one dry dock which can accommodate ships up to 2,250 tons. In addition, one 50-ton and two 30-ton floating cranes, as well as one 15-ton and one 20-ton mobile cranes are available for service to visiting ships. For a detailed description of harbor facilities available in Chinhae, refer to CINCPACFLT Port Directory, Volume V, section B2.

# 13. TROPICAL CYCLONES AFFECTING CHINHAE

## 13.1 CLIMATOLOGY

Refer to section 9.1 for the tropical cyclone climatology of Chinhae.

## 13.2 WIND AND TOPOGRAPHICAL EFFECTS

Maximum winds can be expected from the southeast of Chinhae since little topographic protection is available from this direction. Southeasterly winds would be associated with "threat" tropical cyclone passage to the west of Chinhae.

To determine the extent to which "threat" tropical cyclones produced strong winds ($\geq$ 22 kt) or gale force winds ($\geq$ 34 kt) in Chinhae the wind observations from the Chinhae Air Base (35°08'N, 128°42'E) located on the east side of Haengam Bay (see Figure 44) adjacent to Chinhae Harbor were analyzed. The winds recorded at the Air Base are representative of the wind conditions existing in Chinhae Harbor for all directions except to the south-southeast and west-northwest. Winds from these directions will be 10-20% less at the Airfield due to the protection provided by the two points forming Haengam Bay. Unfortunately, hourly wind observations were only available from 1951-1961.[6] Twenty-one tropical cyclones came within 180 n mi from Chinhae in this 11-year period (June-October); that is, about 2 per year. Table 10 groups the tropical cyclones that "threatened" Chinhae during this period according to the wind intensity that they produced in Chinhae. Of the 21 "threat" tropical cyclones only 33% resulted in strong winds ($\geq$ 22 kt), and 24% resulted in gale force winds ($\geq$ 34 kt).

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[6] This 11-year period represents a very small data base and, therefore, the reader must use caution in applying the conclusions derived from this data.

Table 10. Extent to which "threat" tropical cyclones affected Chinhae during June-October, 1951-1961.

| | | |
|---|---|---|
| Number of tropical cyclones that "threatened" Chinhae | 21 | % |
| Number of "threat" tropical cyclones resulting in strong ($\geq$ 22 kt) winds in Chinhae | 7 | 33% |
| Number of "threat" tropical cyclones resulting in gale force ($\geq$ 34 kt) winds in Chinhae | 5 | 24% |

Figures 45-49 depict the tracks of the "threat" tropical cyclones during the 11-year period 1951-1961. Those resulting in gale force winds at Chinhae during the months of June-October are indicated by a dashed line. "Threat" tropical cyclone tracks resulting in winds less than 34 kt are depicted by a solid line. From analyses of the "threat" tropical cyclone tracks (Figures 45-49) it is apparent that gale force winds resulting from a "threat" tropical cyclone occurred only during August and September.

Figure 50 shows the positions of "threat" tropical cyclone centers when strong winds ($\geq$ 22 kt) were first and last recorded at Chinhae Air Base. It is apparent that "threat" tropical cyclones as far away as 340 n mi may produce winds $\geq$ 22 kt in Chinhae.

Figure 51 shows tropical cyclone center positions when gale force ($\geq$ 34 kt) winds were first and last recorded at Chinhae Air Base. It can be seen that winds $\geq$ 34 kt generally do not begin until the storm is at about 33°N latitude.

The maximum sustained winds recorded at Chinhae Air Base resulted from Typhoon Sarah in 1959 (see Appendix E for a case study on this typhoon). The winds were from the northeast at 55 kt. Figure 44 indicates the presence of hills over 600 ft to the northeast which acted to reduce the wind intensity.

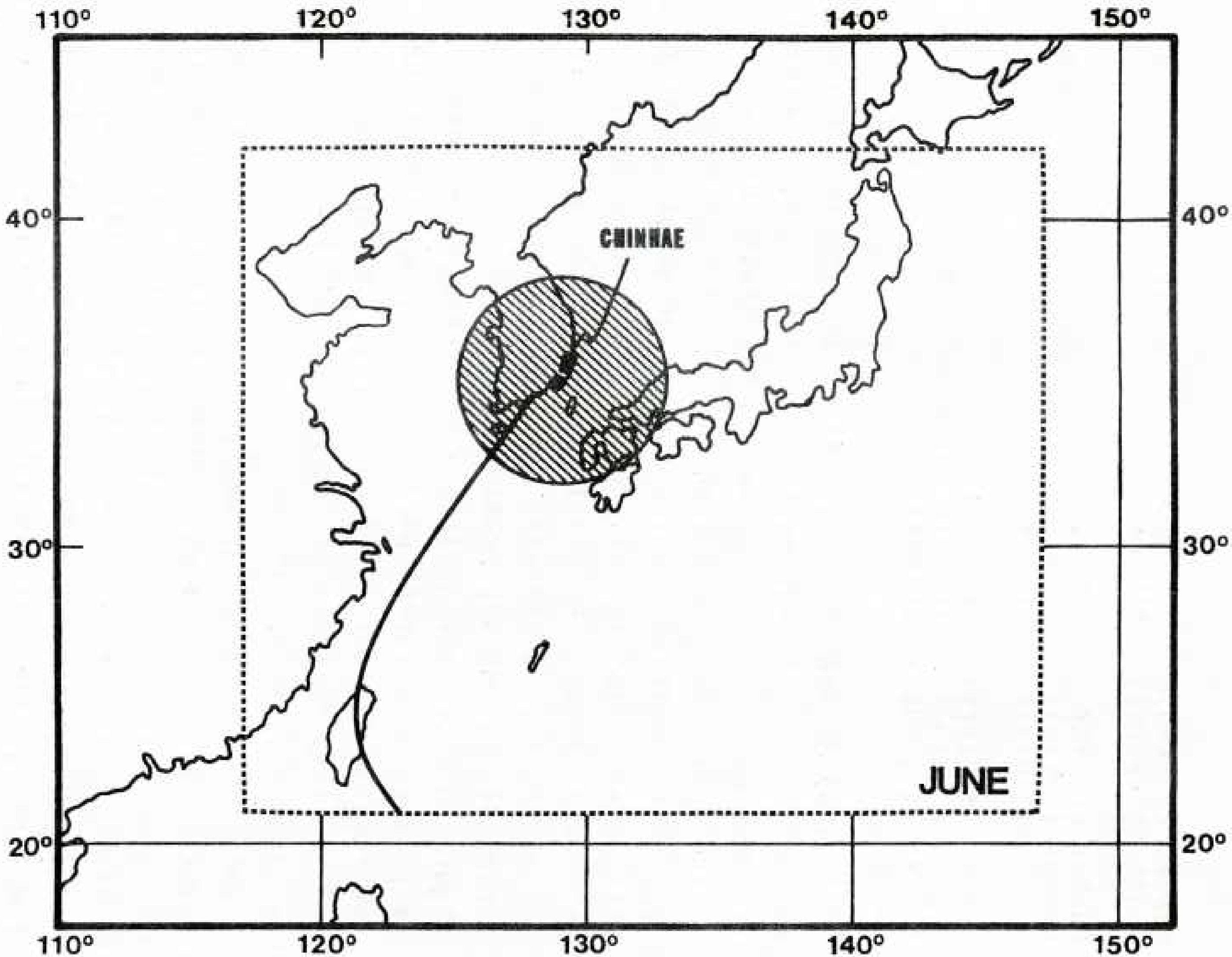


Figure 45. Tracks of tropical cyclones approaching within 180 n mi of Chinhae during the 11-year period, 1951-1961 for June. Dashed line indicates tracks of tropical cyclones that produced winds $\geq$ 34 kt at Chinhae. Solid line indicates tropical cyclones passing within 180 n mi of Chinhae but not producing winds $\geq$ 34 kt at Chinhae.

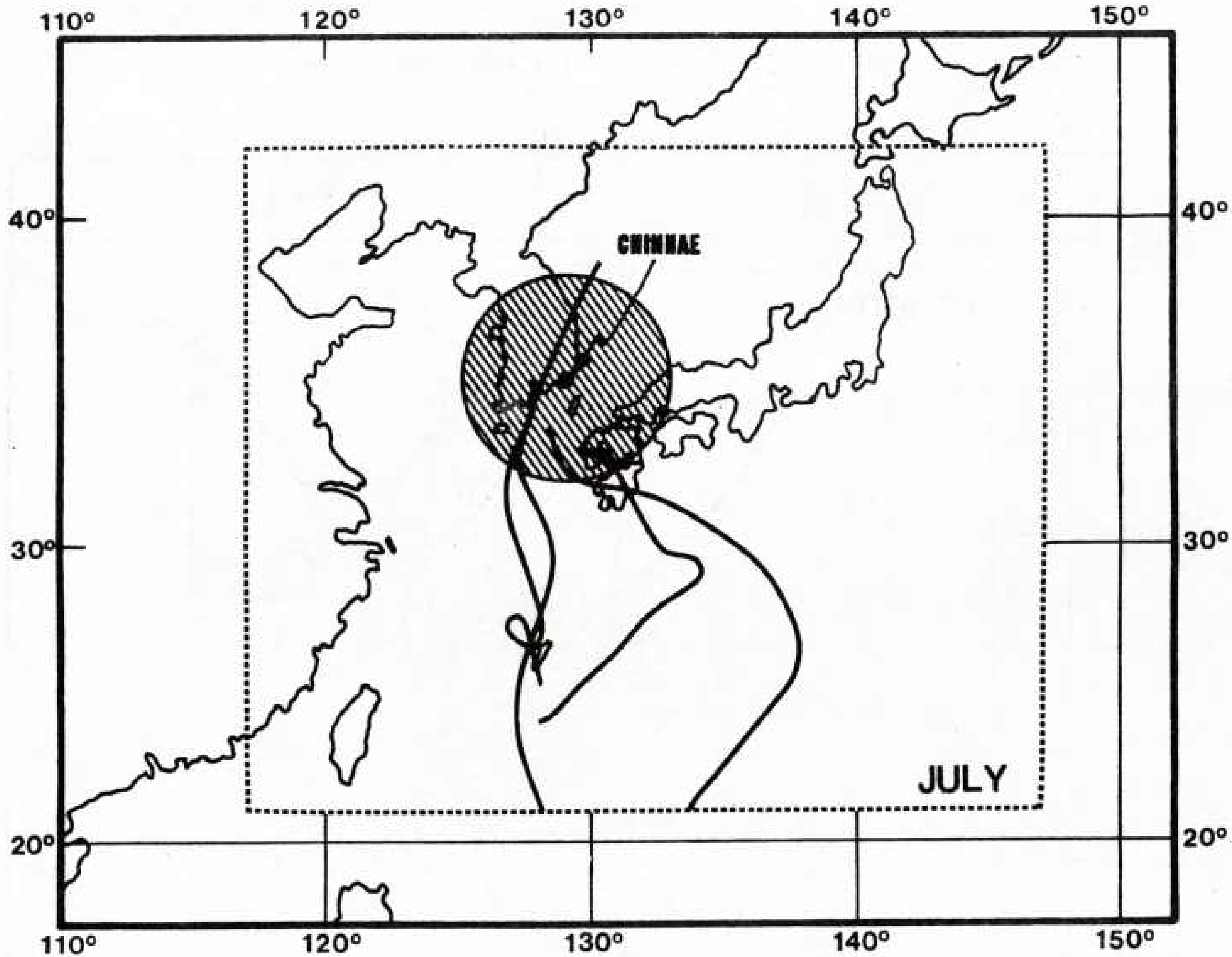


Figure 46. Tracks of tropical cyclones approaching within 180 n mi of Chinhae during the 11-year period, 1951-1961 for July. Dashed line indicates tracks of tropical cyclones that produced winds $\geq$ 34kt at Chinhae. Solid line indicates tropical cyclones passing within 180 n mi of Chinhae but not producing winds $\geq$ 34 kt at Chinhae.

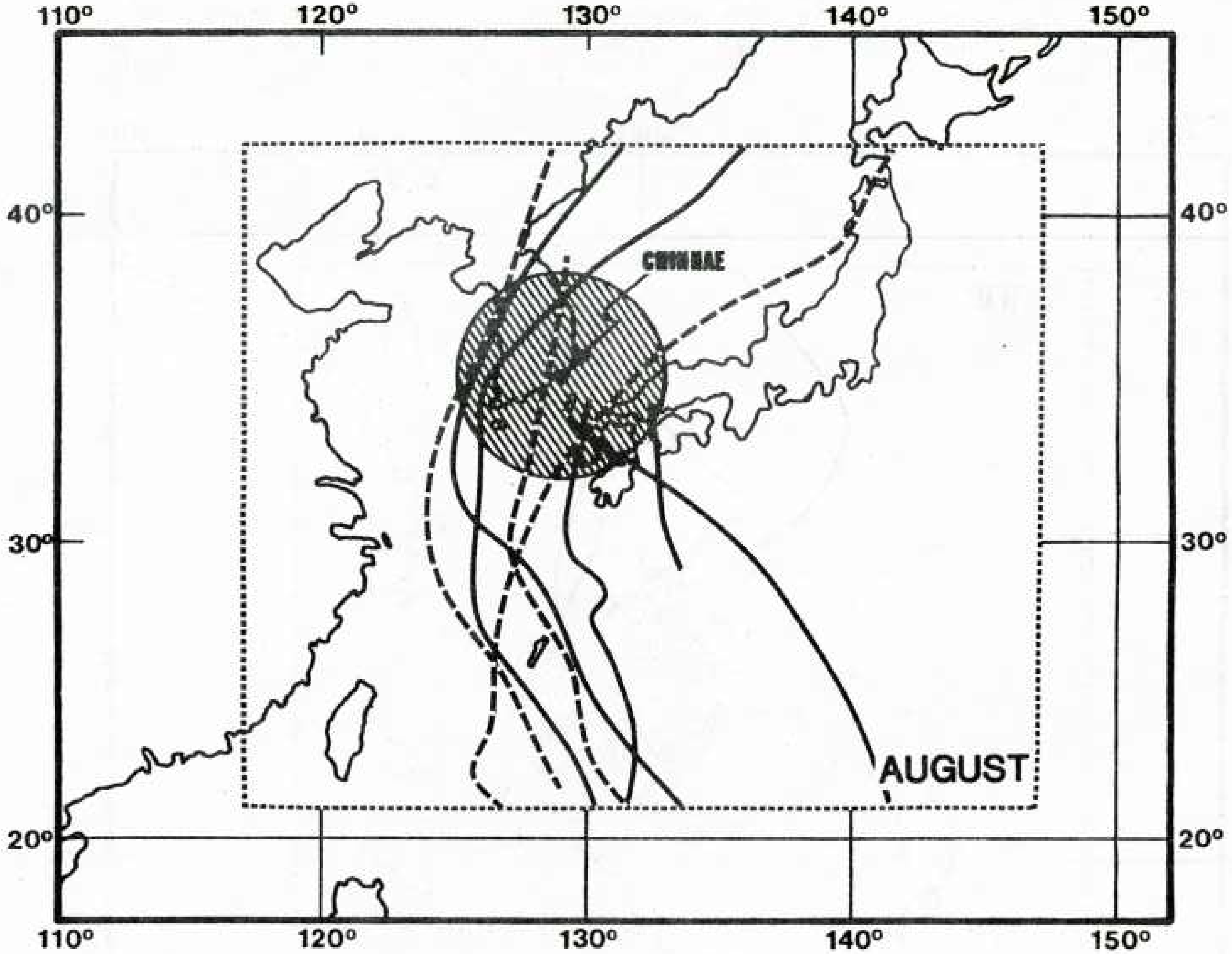


Figure 47. Tracks of tropical cyclones approaching within 180 n mi of Chinhae during the 11-year period, 1951-1961 for August. Dashed line indicates tracks of tropical cyclones that produced winds $\geq$ 34 kt at Chinhae. Solid line indicates tropical cyclones passing within 180 n mi of Chinhae but not producing winds $\geq$ 34 kt at Chinhae.

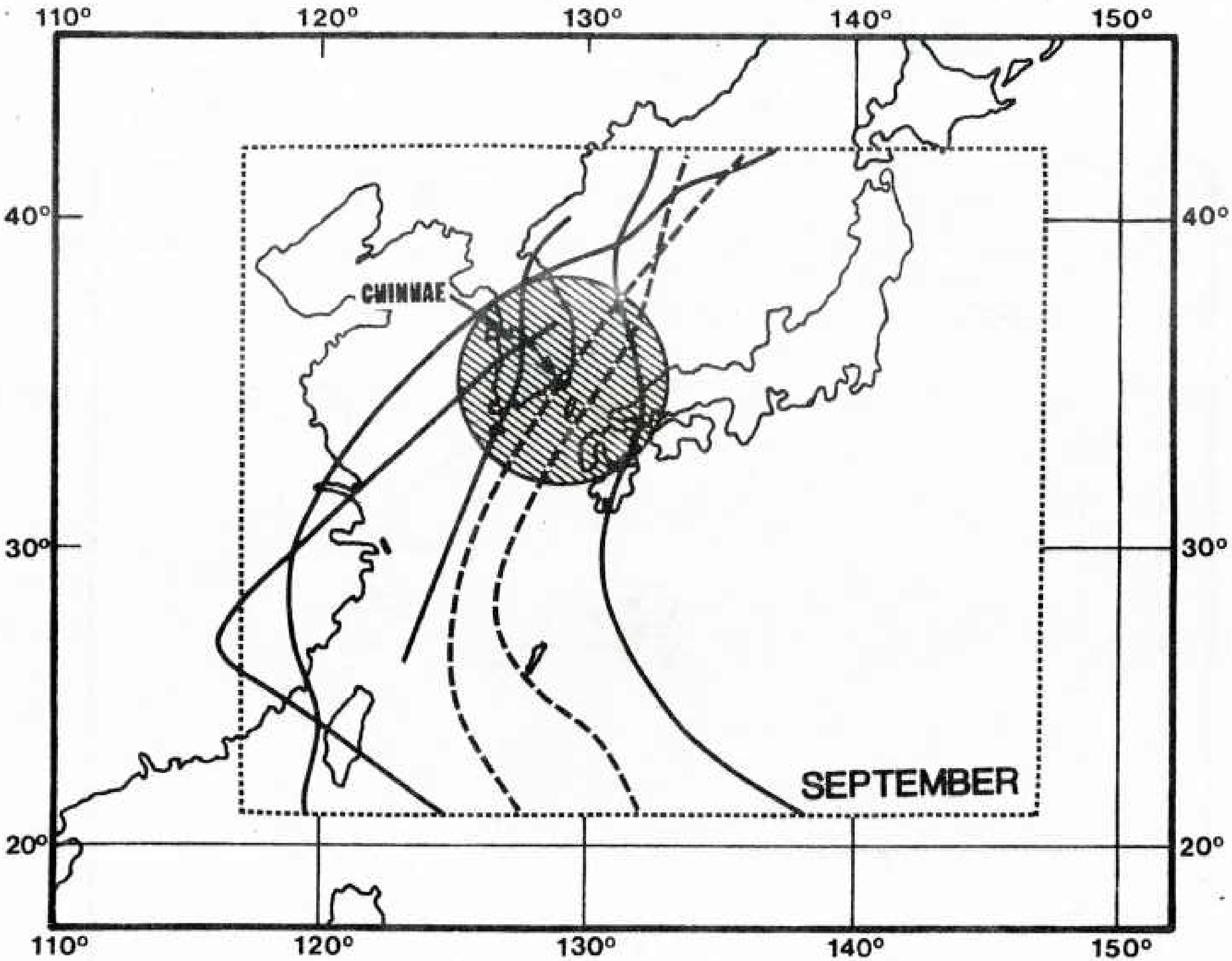


Figure 48. Tracks of tropical cyclones approaching within 180 n mi of Chinhae during the 11-year period, 1951-1961 for September. Dashed line indicates tracks of tropical cyclones that produced winds $\geq$ 34 kt at Chinhae. Solid line indicates tropical cyclones passing within 180 n mi of Chinhae but not producing winds $\geq$ 34 kt at Chinhae.

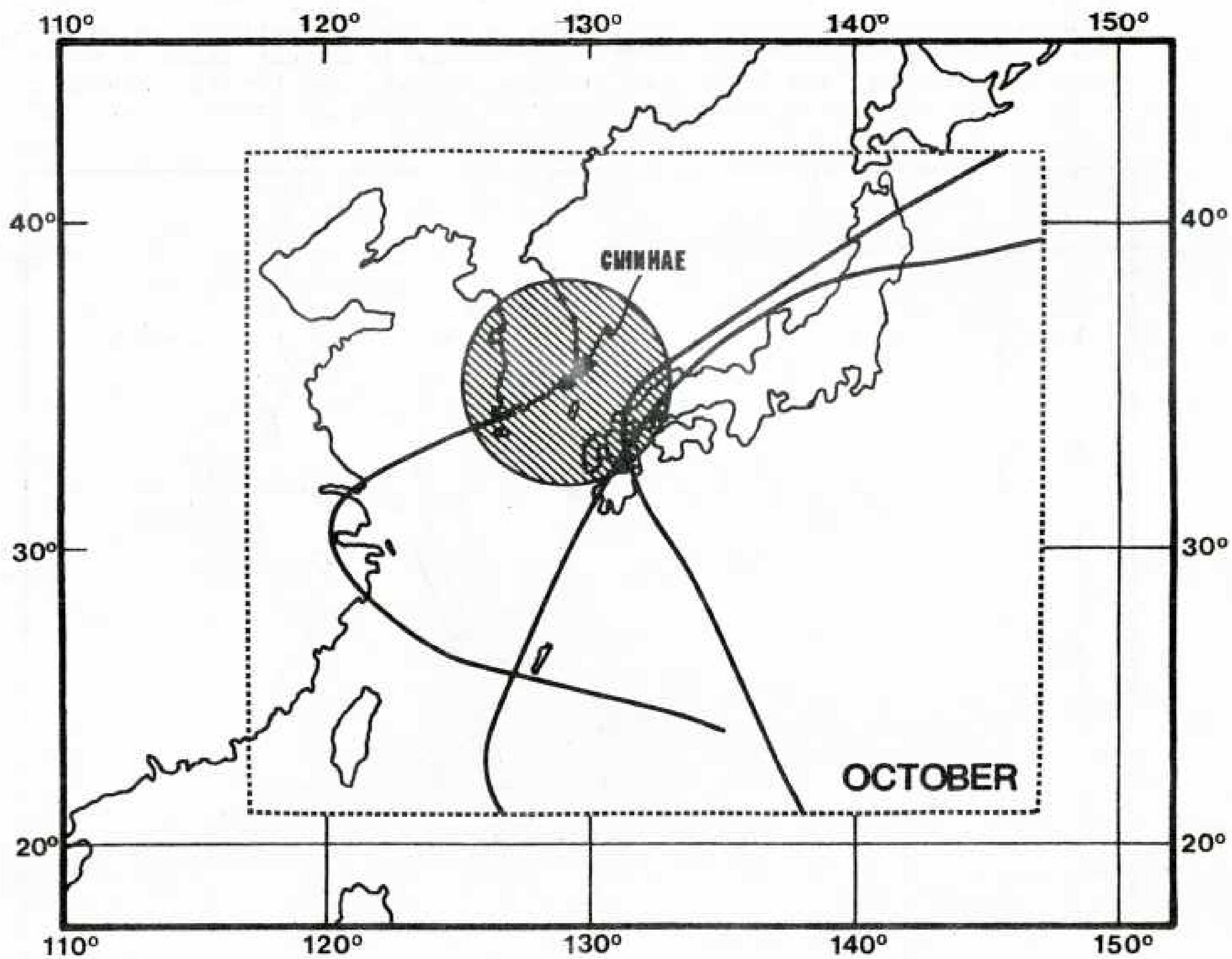


Figure 49. Tracks of tropical cyclones approaching within 180 n mi of Chinhae during the 11-year period, 1951-1961 for October. Dashed line indicates tracks of tropical cyclones that produced winds $\geq$ 34 kt at Chinhae. Solid line indicates tropical cyclones passing within 180 n mi of Chinhae but not producing winds $\geq$ 34 kt at Chinhae.

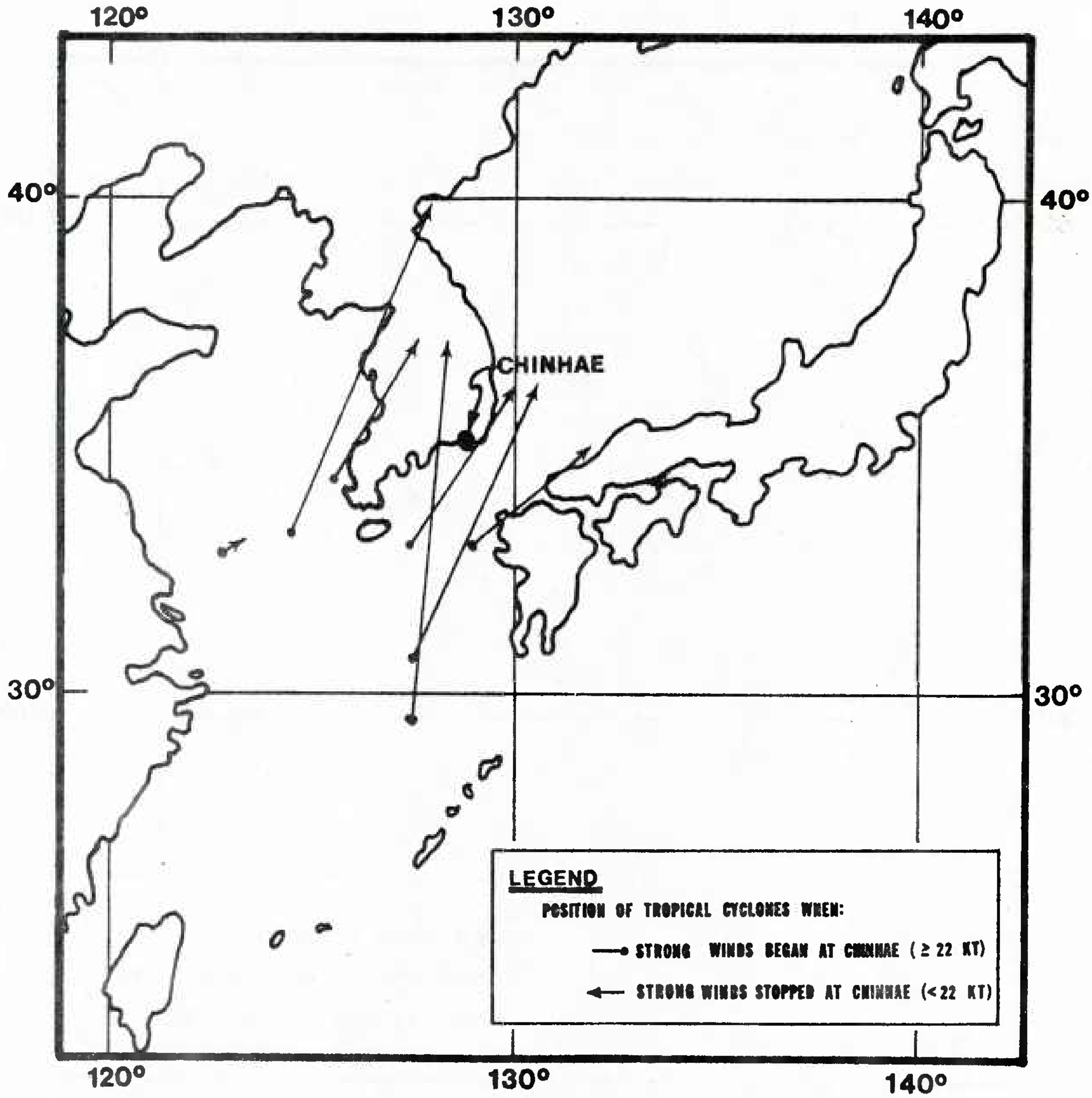


Figure 50. Positions of tropical cyclone centers when $\geq$ 22 kt winds first and last occurred at Chinhae (based on June-October data from the years 1951-1961).

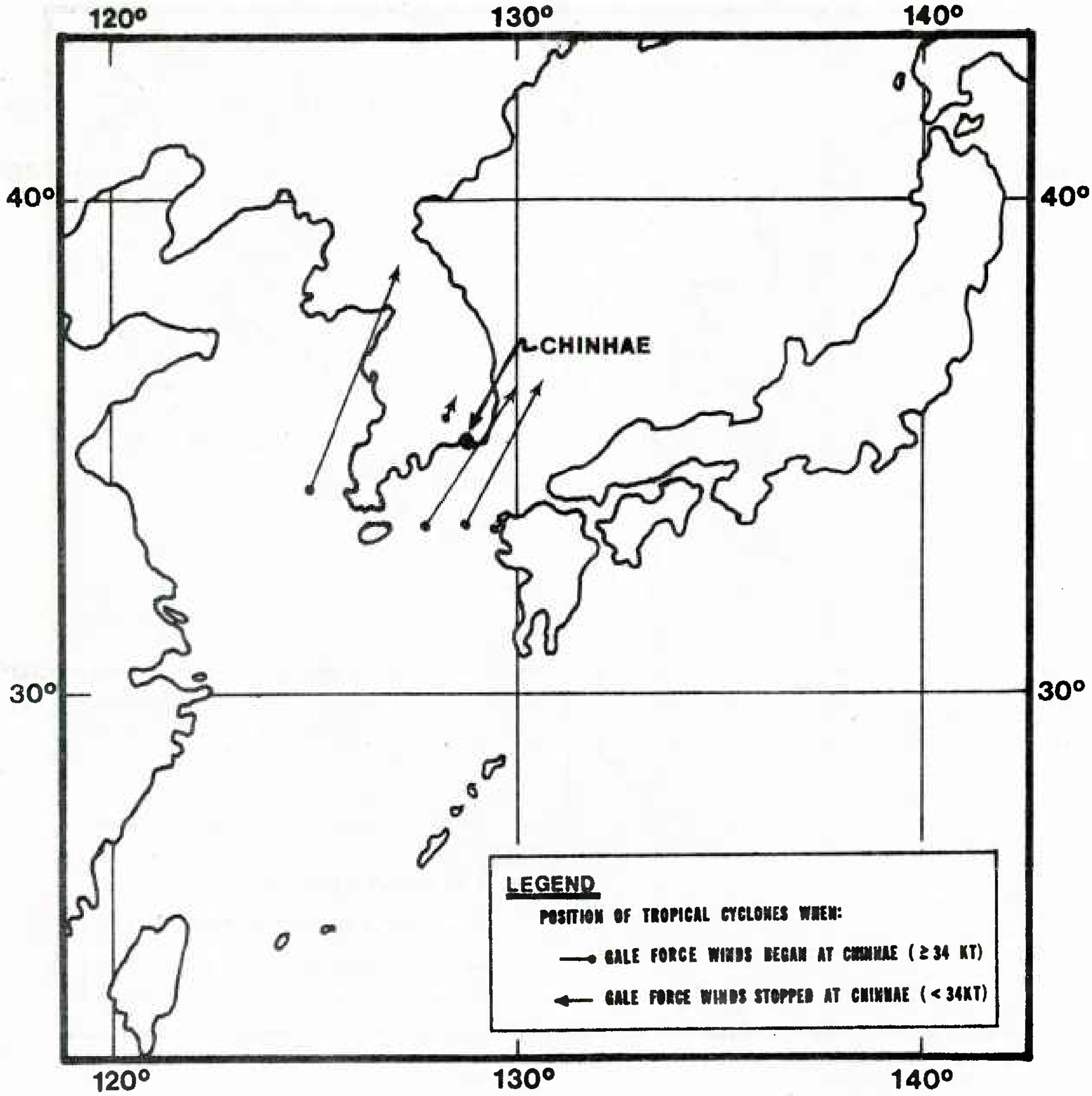


Figure 51. Positions of tropical cyclone centers when $\geq$ 34 kt winds first and last occurred at Chinhae (based on June-October data from the years 1951-1961).

It is felt that the most severe threat to the harbor occurs when a tropical cyclone approaches from the southwest and passes west of Chinhae within 50 n mi. In this case the strongest winds would be from the southeast. This is the direction from which there is almost no topographical protection available and the full force of the typhoon may be felt.

## 13.3 WAVE ACTION

The maximum wave heights that can be expected with typhoon strength winds ($\geq$ 64 kt) in Chinhae Harbor are presented in Table 11.

Table 11. Maximum wave heights that can be expected with typhoon strength winds ($\geq$ 64 kt) in Chinhae Harbor (based on information from U.S. Army Coastal Engineering Research Center, 1973).

| Location | Northern Part of Harbor | Southern Part of Harbor |
|---|---|---|
| Winds generally from the north (tropical cyclone passage east of Chinhae) | 3 ft | 4 ft |
| Winds generally from the south (tropical cyclone passage west of Chinhae) | 10 ft | 8 ft |

## 13.4 STORM SURGE AND TIDES

During periods of moderate to strong southeasterly winds (tropical cyclone passage west of Chinhae), a surge effect is evident in the Inner Harbor. This is caused by wind stress on the water surface and the effects of atmospheric pressure reduction. When this surge effect coincides with high tide, an abnormal rise in water level may occur.

# 14. PREPARATION FOR HEAVY WEATHER AT CHINHAE

## 14.1 TROPICAL CYCLONE WARNINGS

For general information about tropical cyclone warnings the reader is referred to section 6.1.

## 14.2 REMAINING IN PORT

Remaining in port is the recommended course of action for ships of destroyer size or smaller. Larger vessels will find protection in Chinhae Bay.

The only blemish to Chinhae Harbor's typhoon haven status resulted from Typhoon Sarah in 1959. Sarah passed approximately 10 n mi to the east of Chinhae with central winds close to 90 kt. The mountains surrounding Chinhae were effective in reducing the winds substantially but, even though, several ROK Navy vessels were damaged when they ran aground.

## 14.3 EVASION

Evasion from Chinhae Harbor is not necessary when threatened by a tropical cyclone. If evasion is contemplated, evasion technique 1, presented in section 10.3, is recommended.

## 15. CONCLUSION FOR CHINHAE

It is the recommendation of this study that U.S. Navy vessels (destroyer size vessels or smaller) remain in port and that larger vessels seek shelter in Chinhae Bay. If a sortie is desired an evasion route to the Sea of Japan is recommended.

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# APPENDIX A

The mean typhoon tracks, track limits and average speed of movements for the month of June and in 10-day periods for July-October are depicted in Figures A-1 through A-13. It must be realized that storms deviate from the mean tracks, but about 80 percent will fall within the track limits. The use of these tracks should be of particular benefit in long range (in excess of 48 hours) planning. The application of average tracks to the short range specific situation should be avoided (U.S. FWF Sangley Point, 1967).

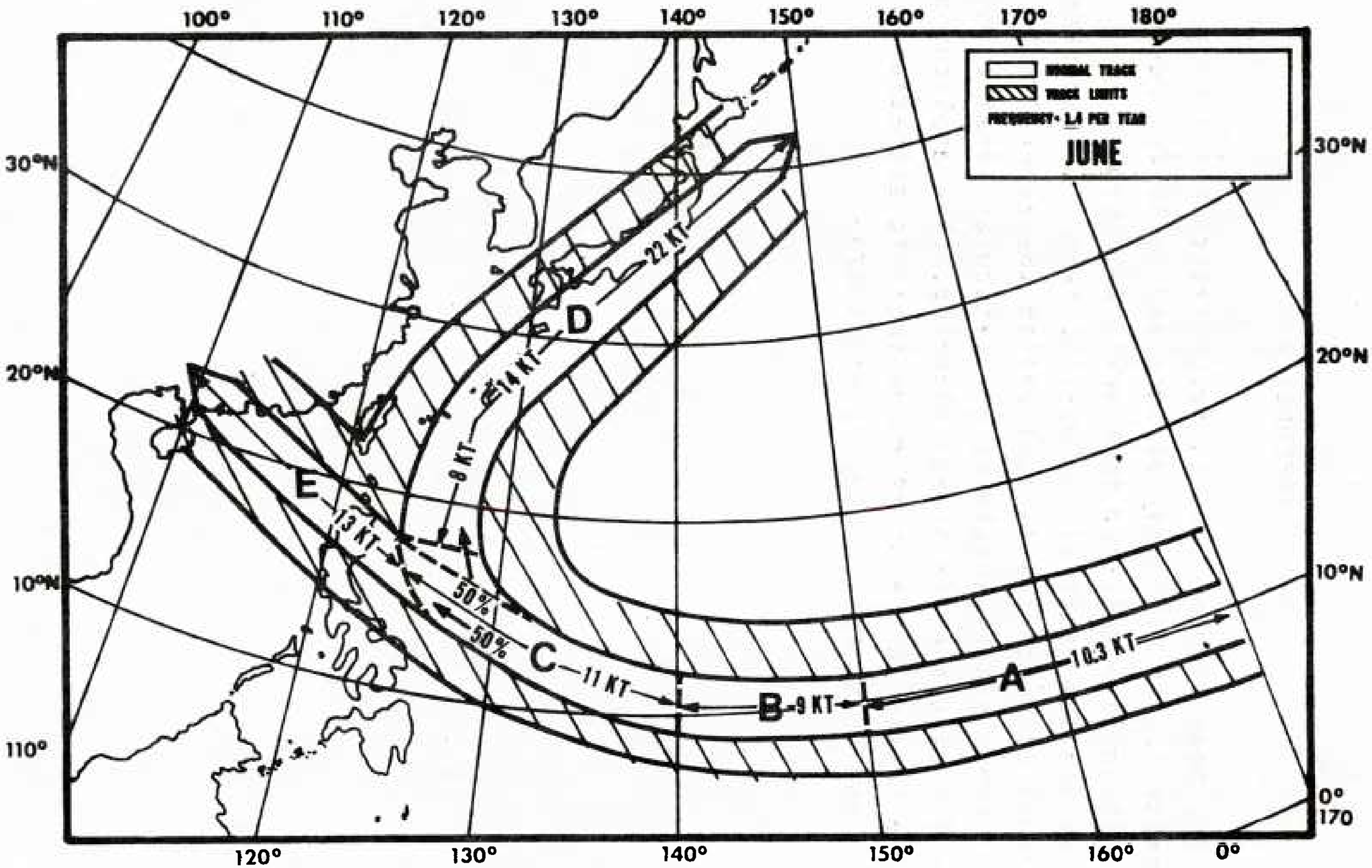



Figure A-1. Mean tropical cyclone track, track limits and average speed of movement for June.

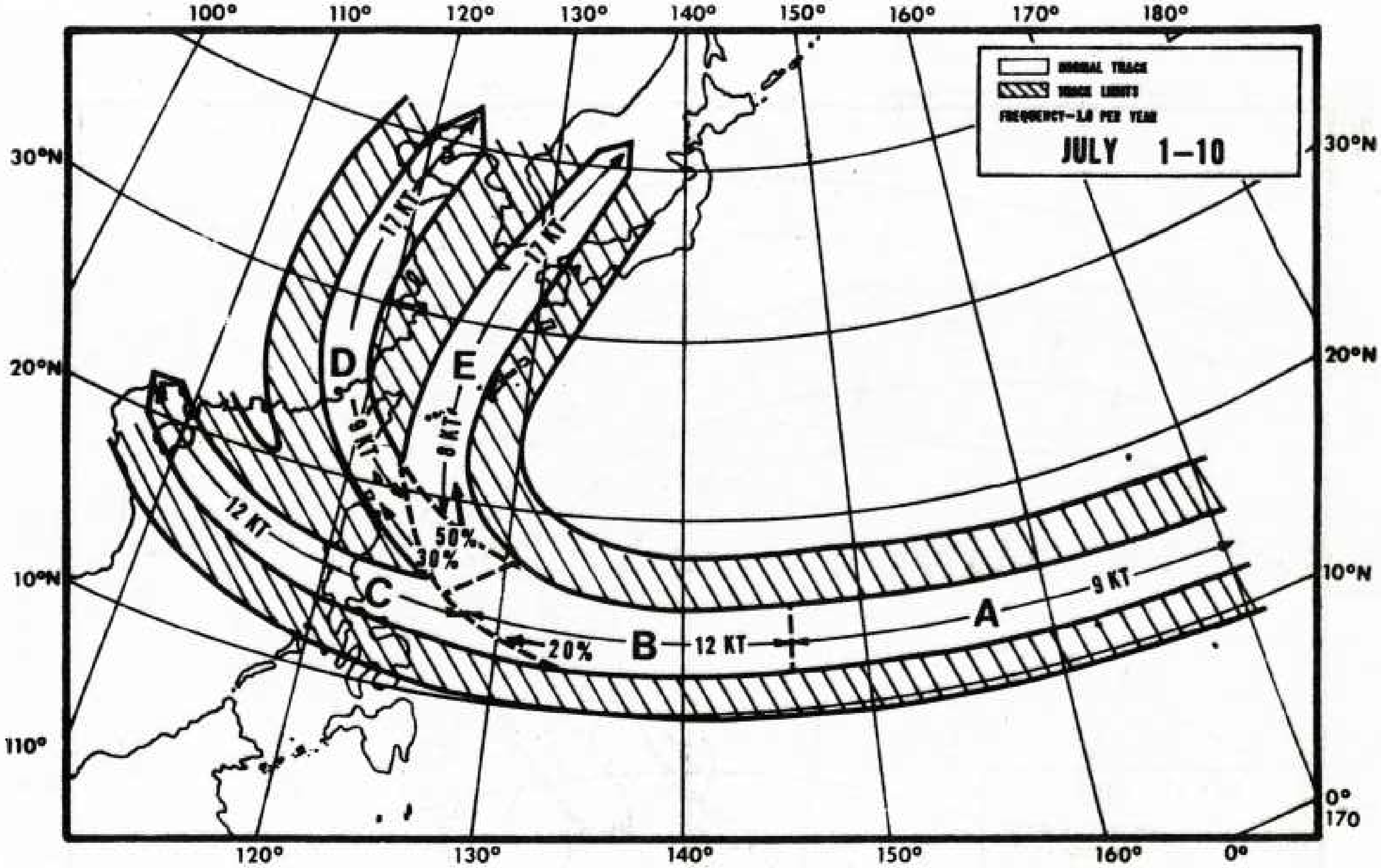



Figure A-2. Mean tropical cyclone track, track limits and average speed of movement for July 1-10.

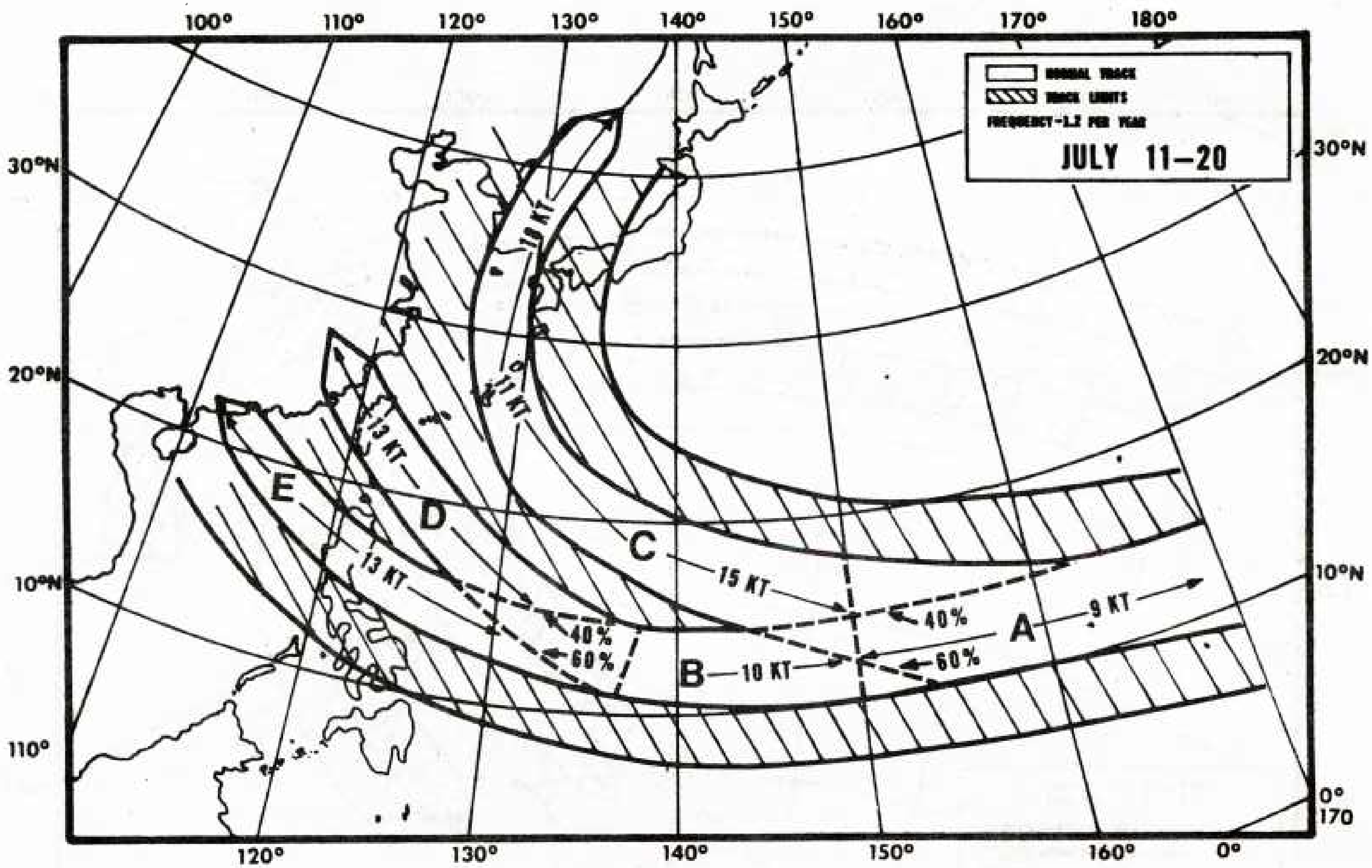



Figure A-3. Mean tropical cyclone track, track limits and average speed of movement for July 11-20.

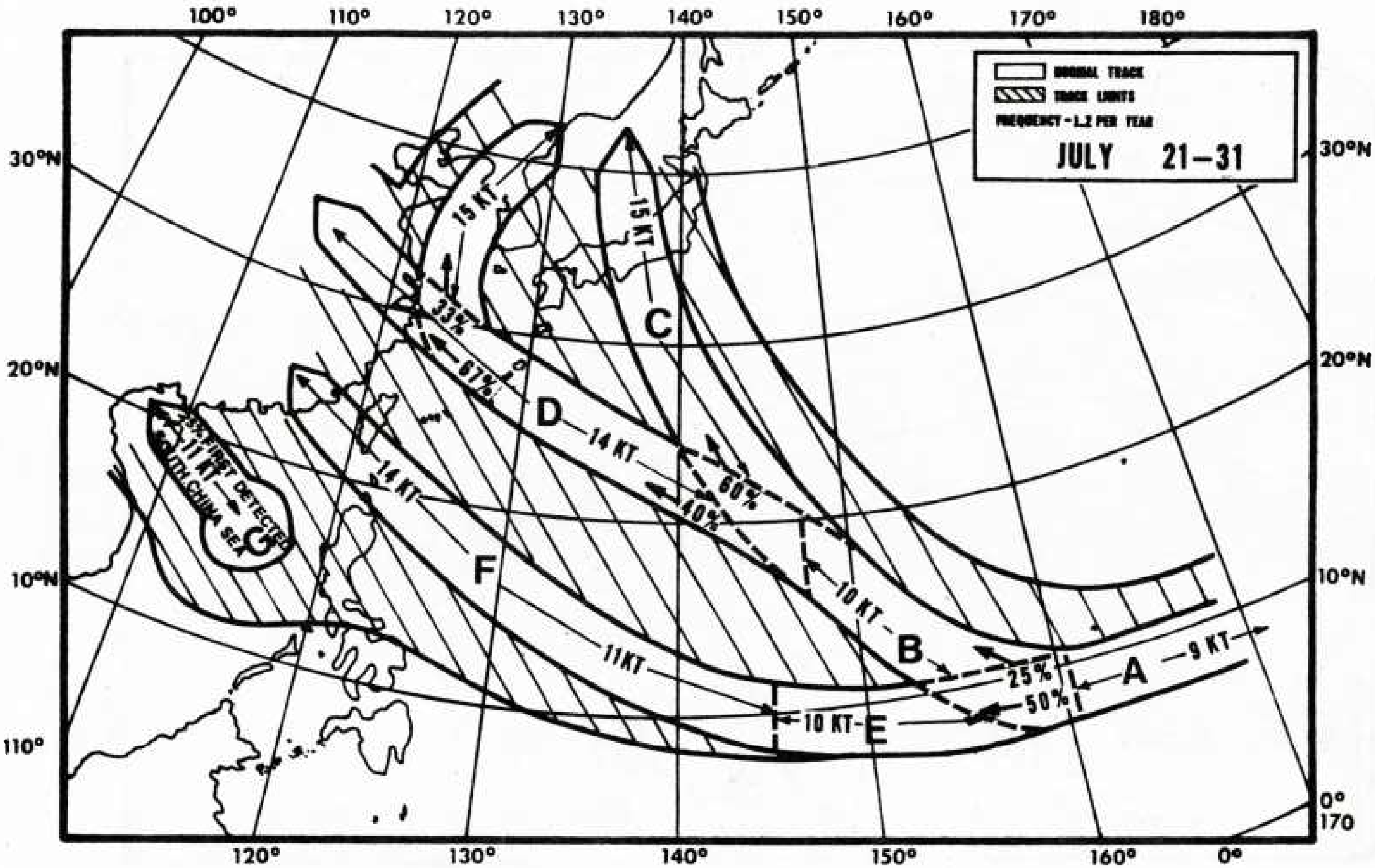



Figure A-4. Mean tropical cyclone track, track limits and average speed of movement for July 21-31.

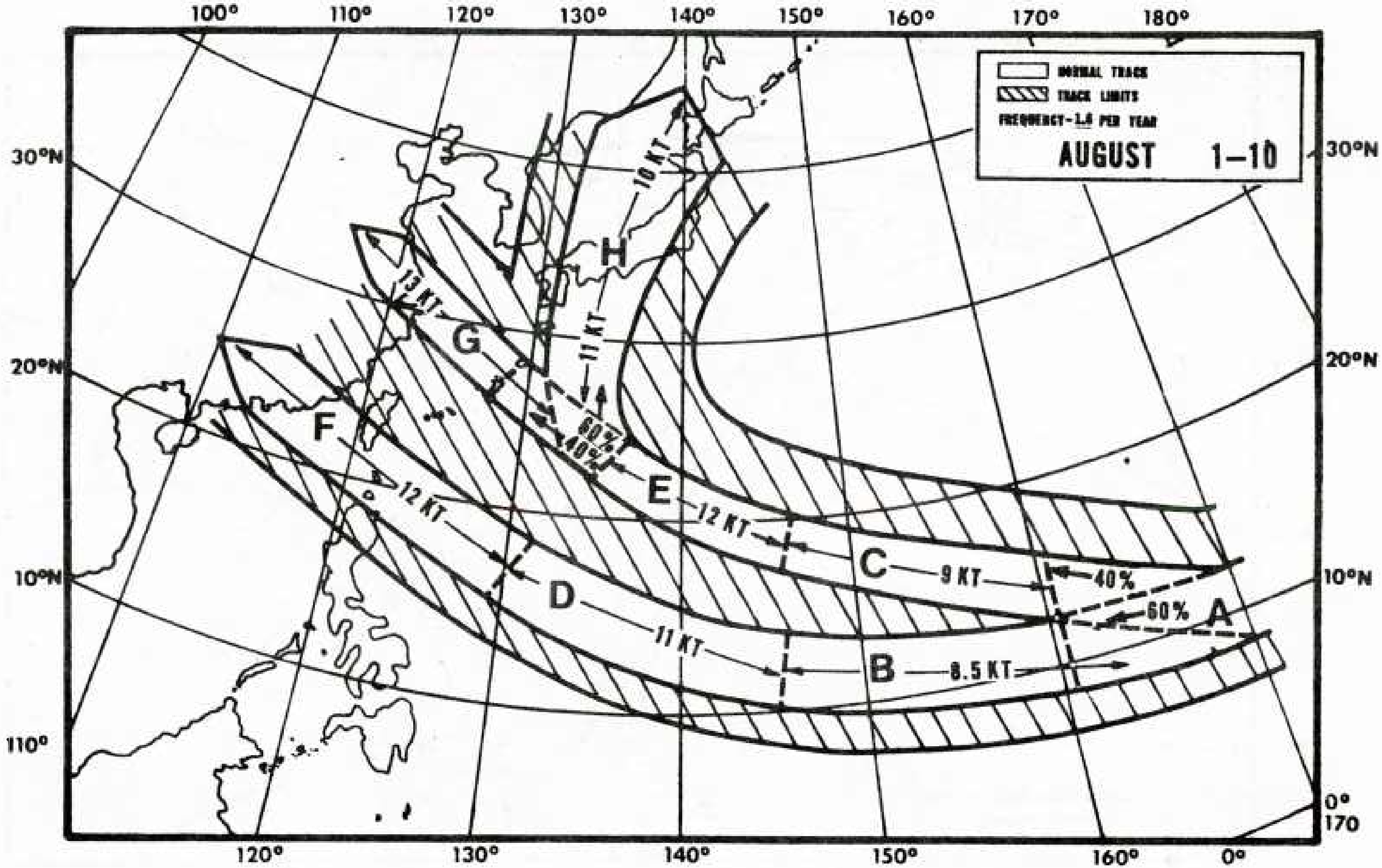



Figure A-5. Mean tropical cyclone track, track limits and average speed of movement for August 1-10.

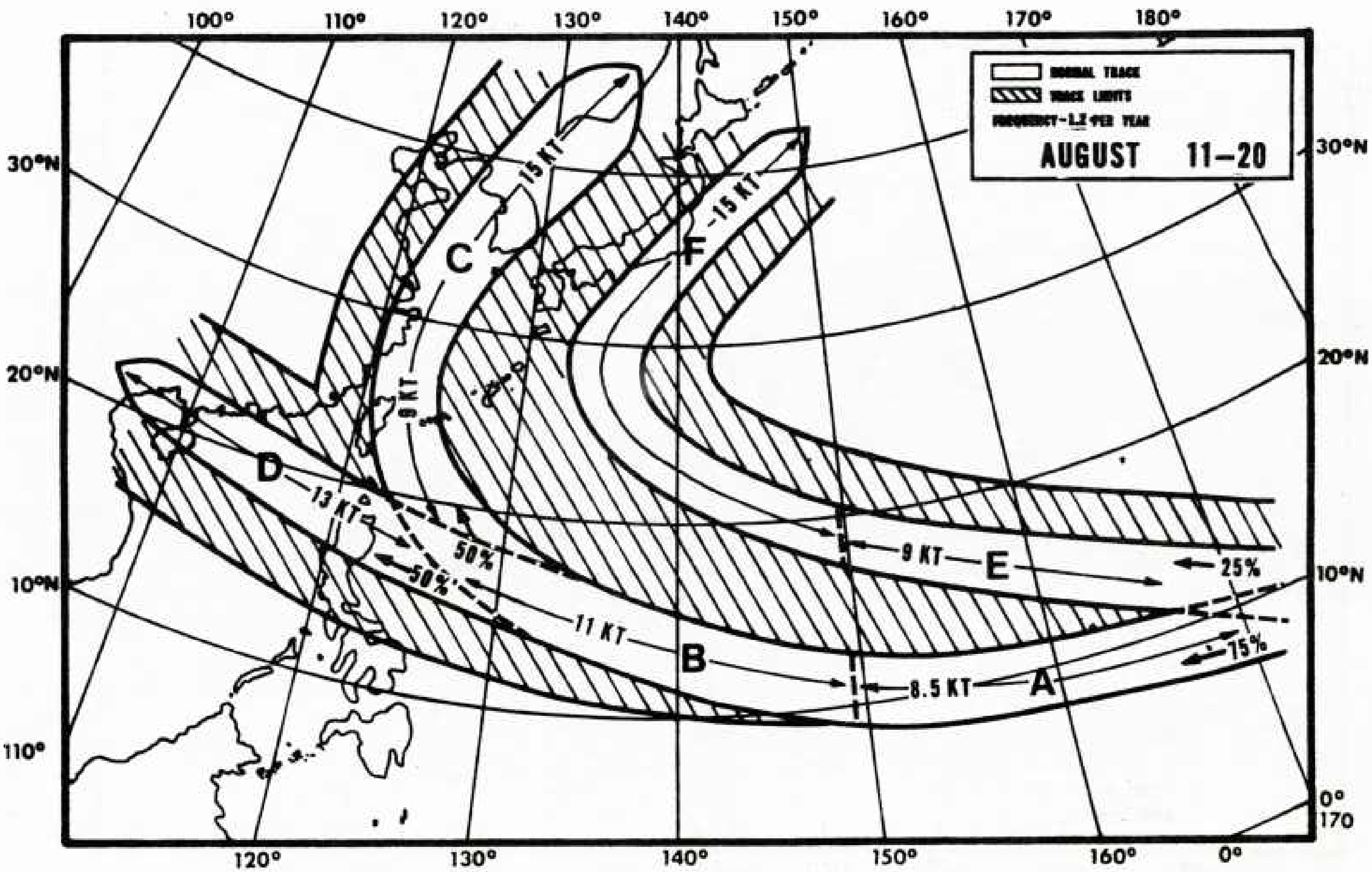



Figure A-6. Mean tropical cyclone track, track limits and average speed of movement for August 11-20.

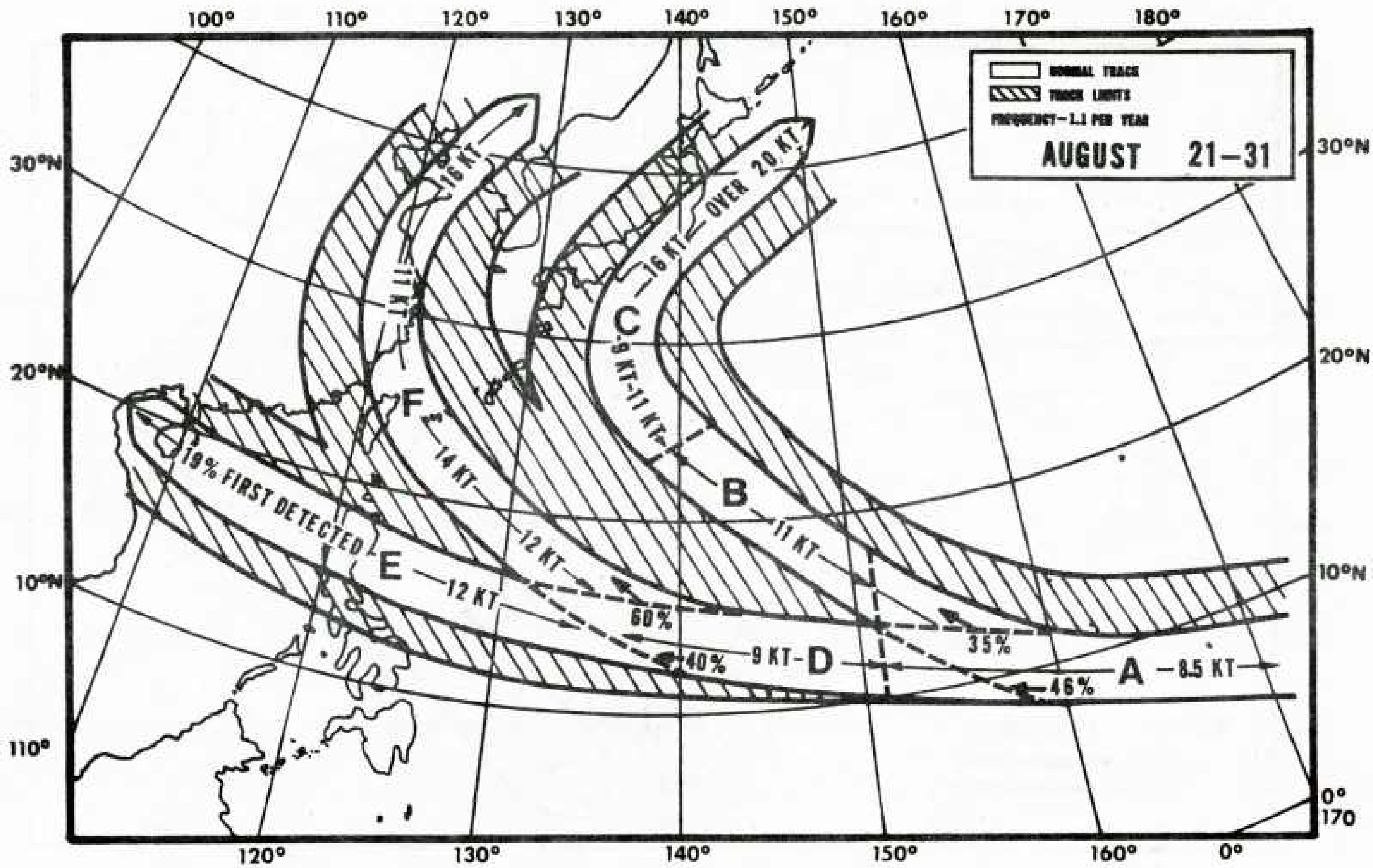



Figure A-7. Mean tropical cyclone track, track limits and average speed of movement for August 21-31.

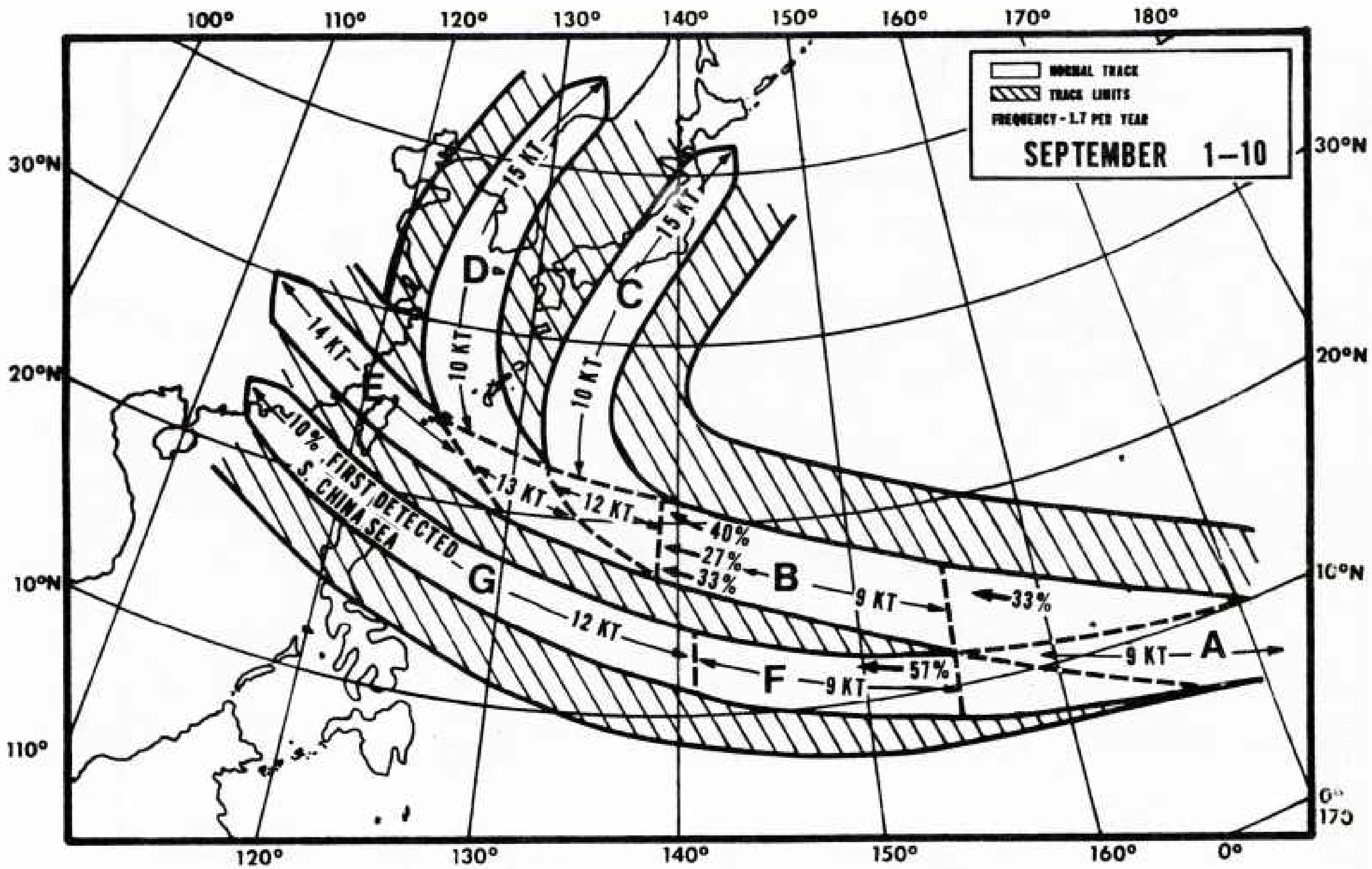



Figure A-8. Mean tropical cyclone track, track limits and average speed of movement for September 1-10.

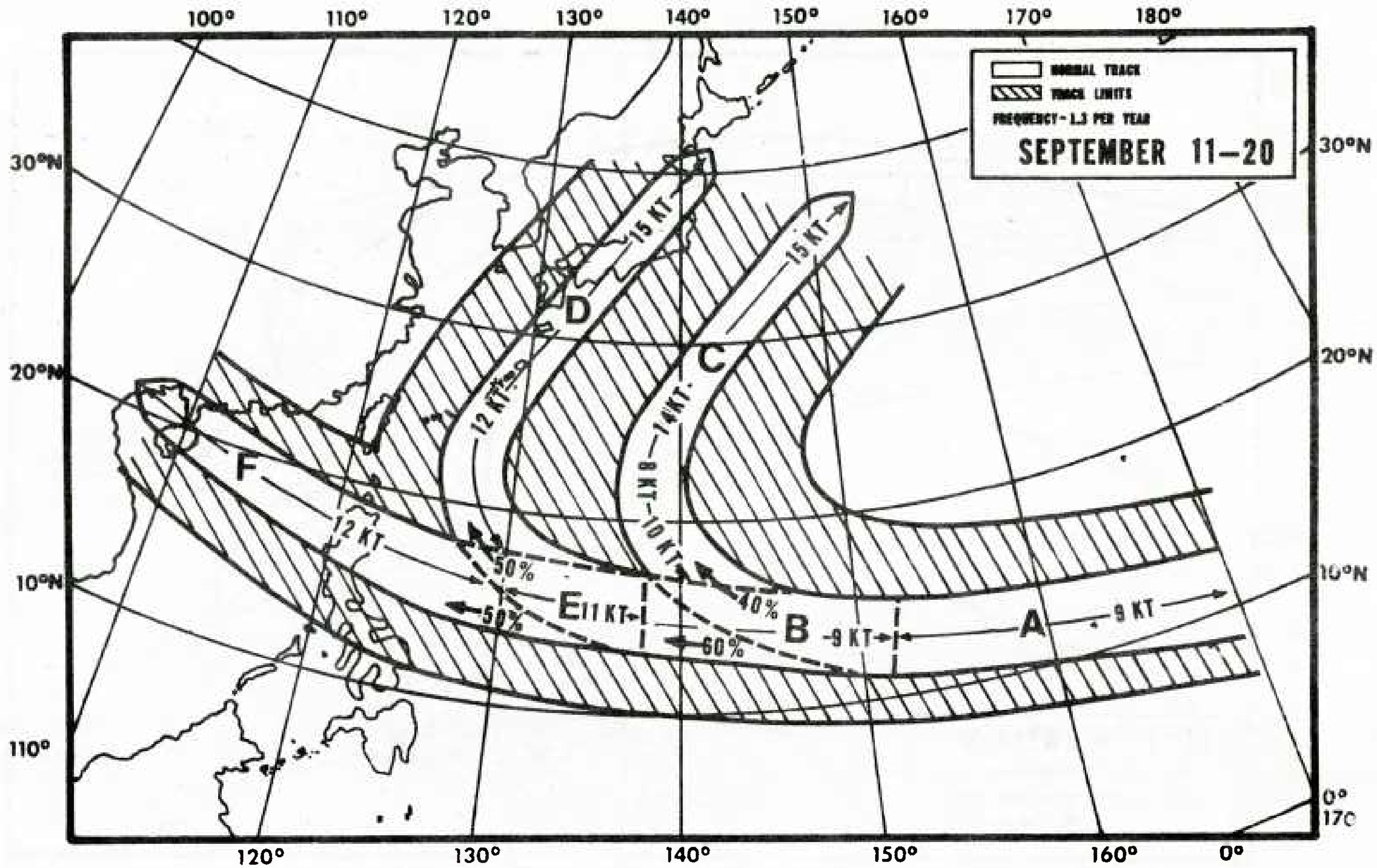



Figure A-9. Mean tropical cyclone track, track limits and average speed of movement for September 11-20.

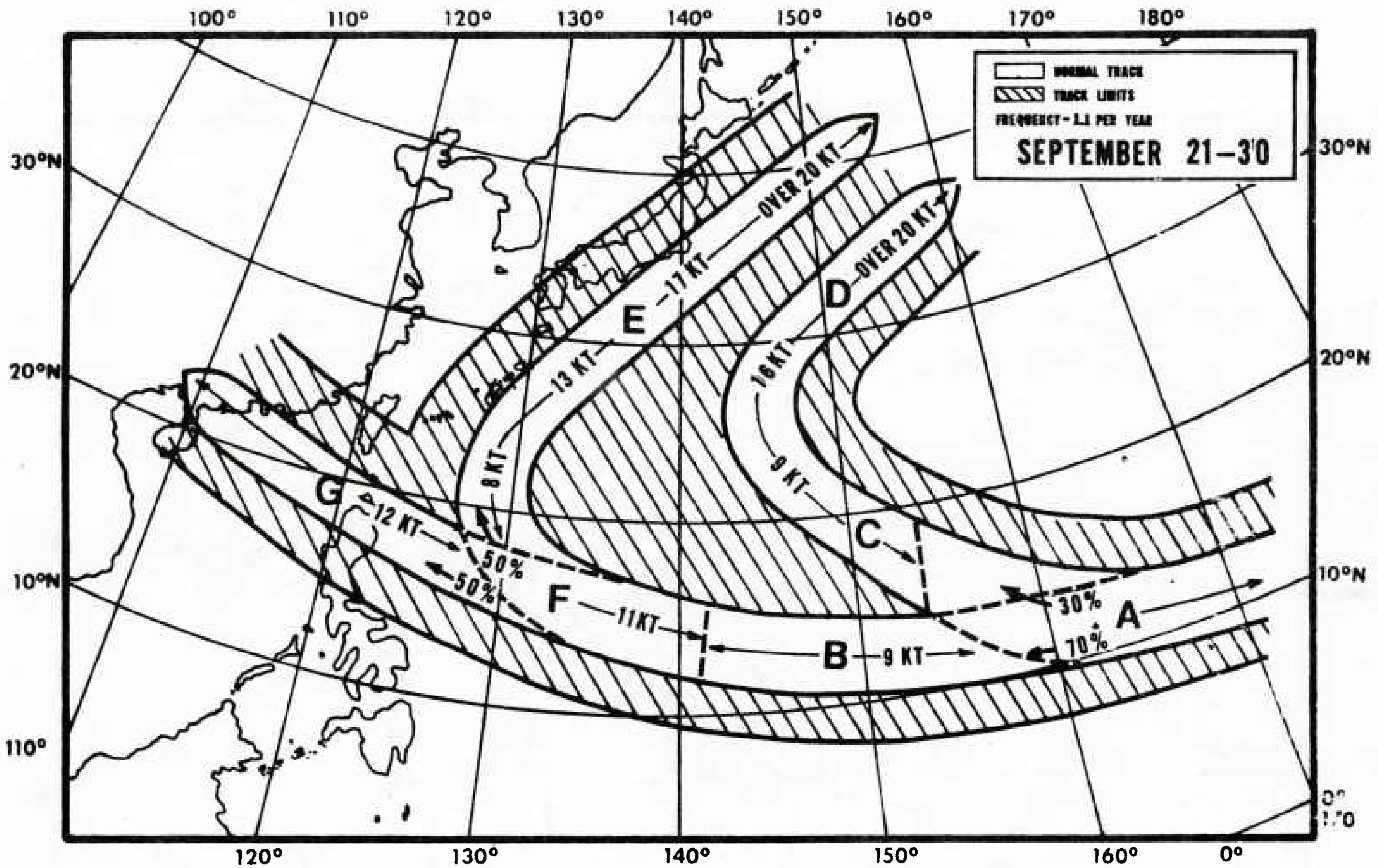



Figure A-10. Mean tropical cyclone track, track limits and average speed of movement for September 21-30.

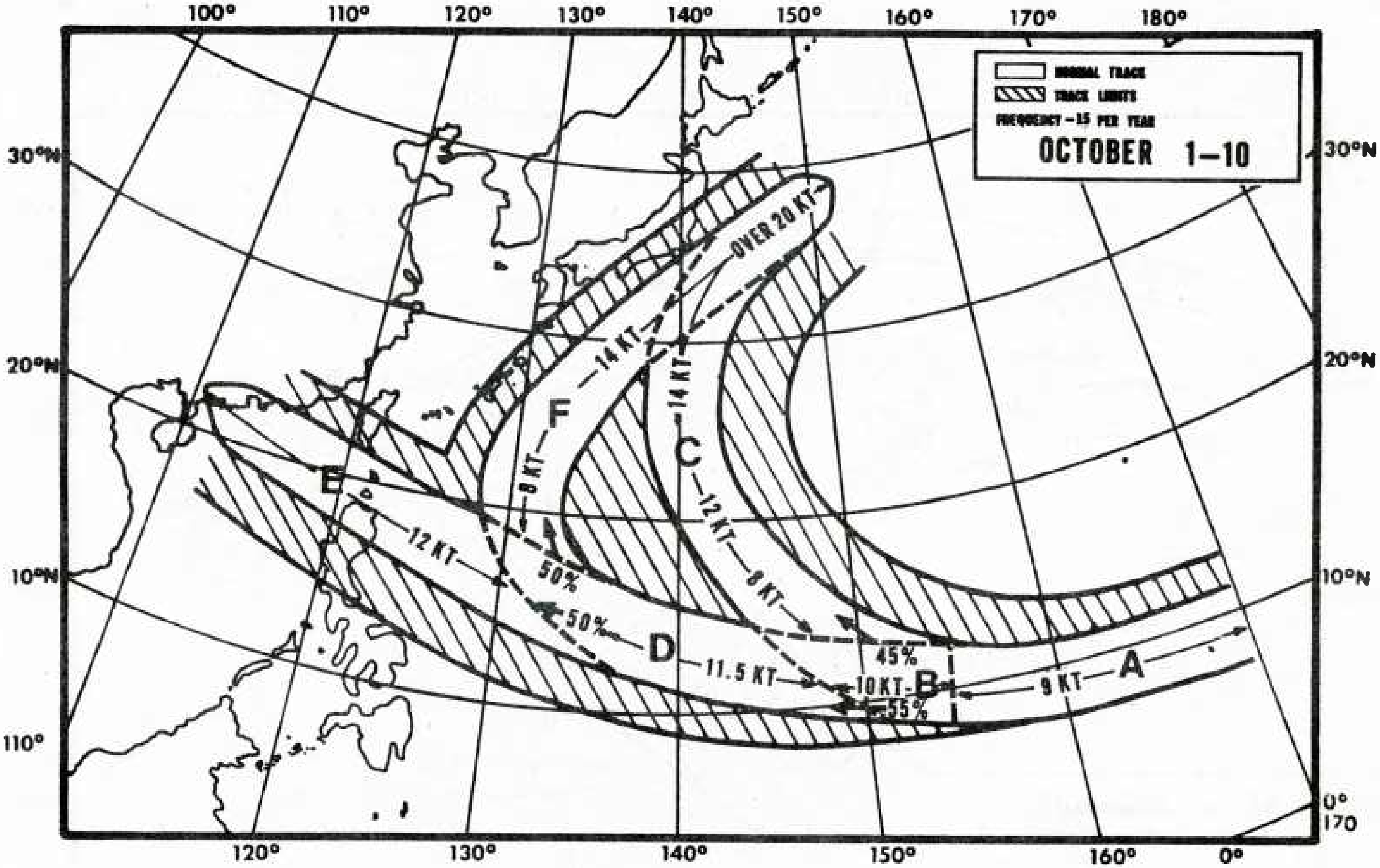



Figure A-11. Mean tropical cyclone track, track limits and average speed of movement for October 1-10.

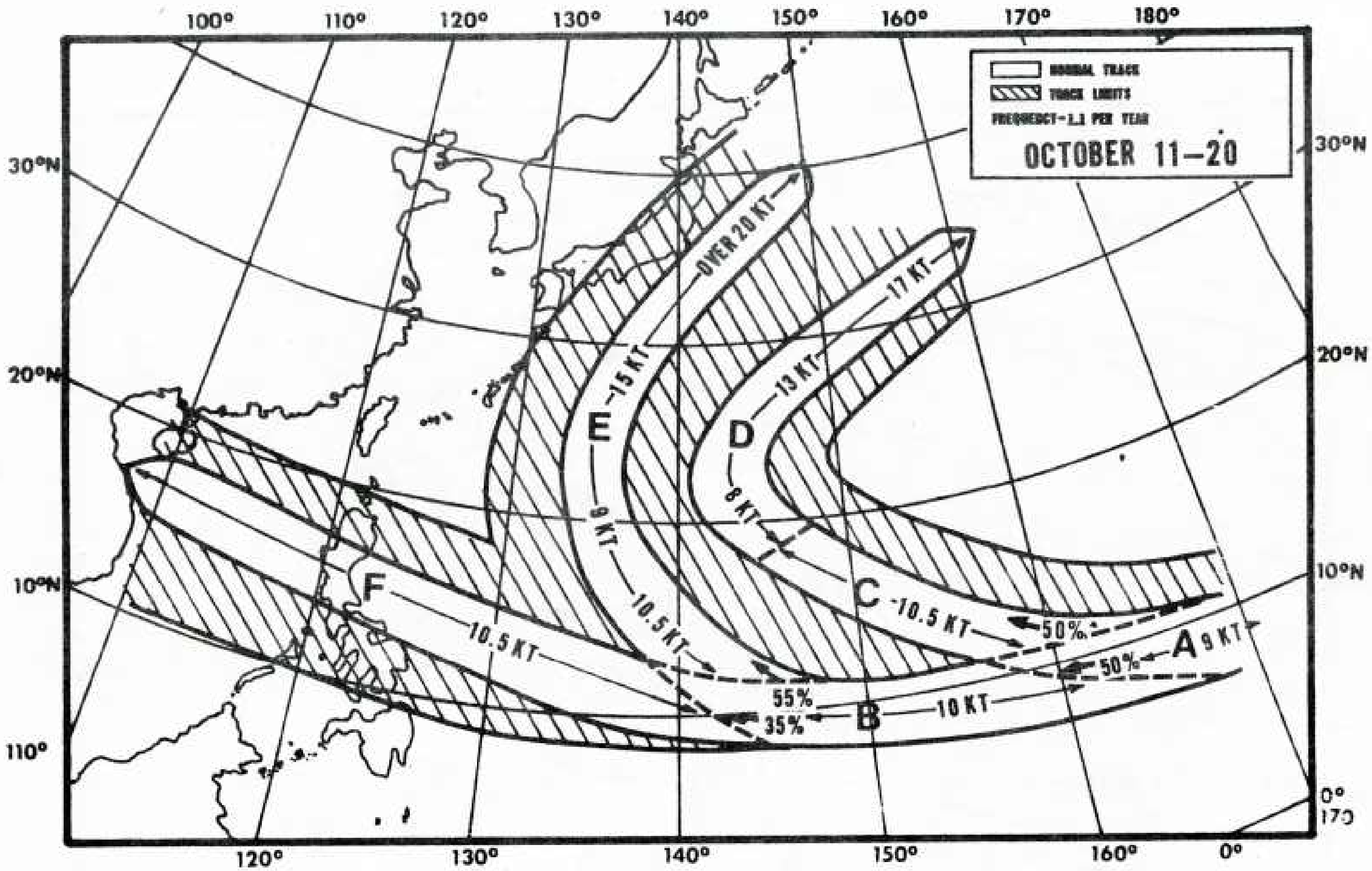



Figure A-12. Mean tropical cyclone track, track limits and average speed of movement for October 11-20.

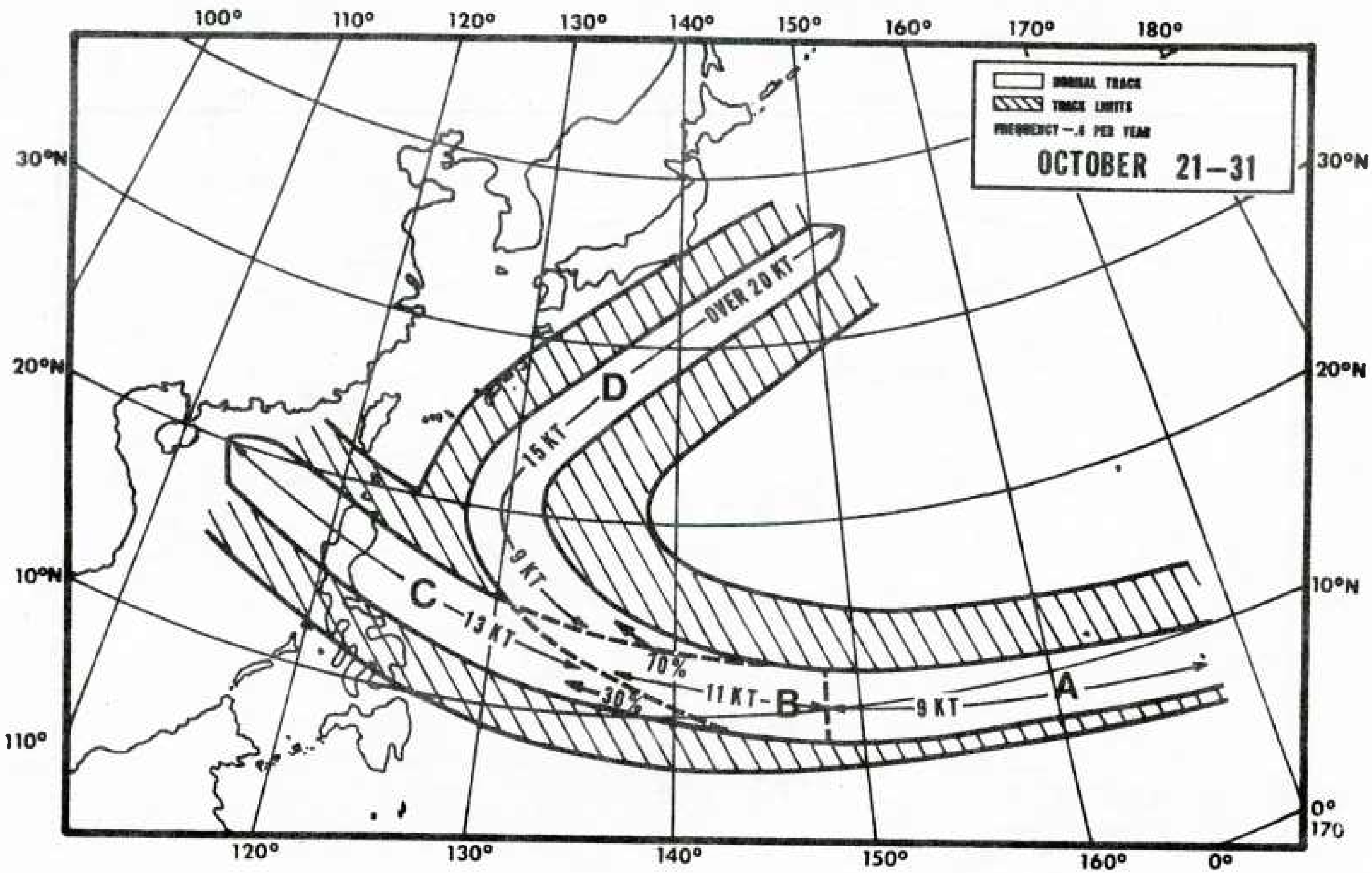



Figure A-13. Mean tropical cyclone track, track limits and average speed of movement for October 21-31.

## APPENDIX B

## INCHON HARBOR TIDAL BASIN BERTHING INFORMATION

A. BERTHING FACILITIES IN THE TIDAL BASIN

1. Inchon Port is controlled and managed by the office of the Marine Bureau, Ministry of Transportation within the harbor limits of 10,000 meters in radius at/from the north corner of Pier One Lock entrance, consisting of 1,510 square km of the wet dock area and 23,000 square km of the Outer Harbor.

2. Berthing Capacity is as Follows (Tidal Basin Area):

| Gross Tons | Number of Berths Available |
|---|---|
| 2,000 Tonners | 4 Berth |
| 4,500 " | 3 " |
| 8,000 " | 9 " |
| 10,000 " | 3 " |
| 20,000 " | 3 " |
| 30,000 " | 1 " |
| 40,000 " | 1 " |
| 50,000 " | 1 " |

The depths of basin are 12-14m (36'-42').

A total of 25 vessels of various sizes can be simultaneously accommodated, and those vessels will be berthed in four (4) piers in the basin area.

Pier One maintains three berths (1-3) for 2,000/3,000 tonners.

Pier Two maintains ten berths (4-13) for 3,000/15,000 tonners.

Pier Three maintains seven berths (14-20) for 8,000/15,000 tonners.

Pier Four maintains five berths (21-25) for 15,000/50,000 tonners.

3. Lock Chamber:

| Lock Chamber Specification | Up to 50,000 G/Tonners | Up to 10,000 G/Tonners |
|---|---|---|
| Length <u>Over All</u> | | |
| Inner gate side | 271 Meters | 176 Meters |
| Outer gate side | 301 Meters | 201 Meters |
| Width <u>Over All</u> (Beam) | 36 Meters | 22.5 Meters |
| Height <u>Over All</u> | | |
| Frame lock sill | 18.50 Meters | 18.5 Meters |
| Frame lock chamber | 19 Meters | 19 Meters |

4. Lock Gates:

| Gate Specification | Up to 50,000 G/Tonners | Up to 10,000 G/Tonners |
|---|---|---|
| Length <u>Over All</u> | 38 Meters | 24.5 Meters |
| Height <u>Over All</u> | 18.5 Meters | 18.5 Meters |
| Width <u>Over All</u> | 8.3 Meters | 6.4 Meters |
| Weight | 1,050 K/Tons | 590 K/Tons |
| Opening/Closing Time | 5 Minutes | 4 Minutes |

## B. <u>STREAM ANCHORAGES</u>

Listed below are the anchorages reserved for the vessels awaiting berthing instructions in the basin or discharging logs, POL products and other dangerous cargo as specified by the director of the Marine Affairs.

1. "ALFA" Anchorage

| ANCHORAGE | POSITION | DEPTH (at low tide) | REMARKS |
|---|---|---|---|
| ALFA-1 | 37°29'56"N, 126°36'05"E | 41' | Open |
| ALFA-2 | 37°29'32"N, 126°36'02"E | 30' | " |
| ALFA-3 | 37°20'15"N, 126°35'44"E | 42' | " |
| ALFA-4 | 37°28'56"N, 126°35'25"E | 30' | " |
| ALFA-5 | 37°28'33"N, 126°35'20"E | 24' | " |
| ALFA-6 | 37°28'11"N, 126°36'08"E | 36' | Reserved |
| ALFA-7 | 37°27'57"N, 126°35'30"E | 30'* | |
| ALFA-8 | 37°27'23"N, 126°35'04"E | 36' | Open |

*Not useable

2. "BRAVO" Anchorage

| ANCHORAGE | POSITION | DEPTH (at low tide) | REMARKS |
|---|---|---|---|
| BRAVO-1 | 37°27'22"N, 126°34'59"E | 30' | Reserved |
| BRAVO-2 | 37°26'54"N, 126°34'45"E | 30' | " |
| BRAVO-3 | 36°26'24"N, 126°34'35"E | 30' | " |
| BRAVO-4 | 37°26'35"N, 126°34'24"E | 30' | Open |
| BRAVO-5 | 37°25'27"N, 126°35'13"E | 36' | " |
| BRAVO-6 | 37°34'58"N, 126°33'58"E | 42' | " |
| BRAVO-7 | 37°27'00"N, 126°36'25"E | 42' | Reserved |
| BRAVO-8 | 37°26'30"N, 126°35'11"E | 30' | " |
| BRAVO-9 | 37°26'00"N, 126°35'02"E | 36' | Open |
| BRAVO-10 | 37°25'032"E, 126°34'51"E | 42' | " |
| BRAVO-11 | 37°25'08"N, 126°34'36"E | 42' | " |

3. "CHARLIE" Anchorage

| ANCHORAGE | POSITION | DEPTH (at low tide) | REMARKS |
|---|---|---|---|
| CHARLIE-1 | 37°24'29"N, 126°34'26"E | 36' | Open |
| CHARLIE-2 | 37°24'07"N, 126°34'17"E | 35' | " |
| CHARLIE-3 | 37°21'37"N, 126°34'08"E | 33' | " |
| CHARLIE-4 | 37°21'21"N, 126°33'55"E | 36' | " |
| CHARLIE-5 | 37°24'37"N, 126°34'52"E | 28' | " |
| CHARLIE-6 | 27°24'10"N, 126°24'45"E | 30' | " |
| CHARLIE-7 | 37°23'47"N, 126°34'36"E | 24' | " |
| CHARLIE-8 | 37°23'25"N, 126°24'21"E | 21' | " |

4. "DELTA" Anchorage

| ANCHORAGE | POSITION | DEPTH (at low tide) | REMARKS |
|---|---|---|---|
| DELTA-1 | 37°29'45"N, 126°36'30"E | 33' | Open for Logcarriers |
| DELTA-2 | 37°29'28"N, 126°36'18°E | 33' | " |
| DELTA-3 | 37°29'15"N, 126°36'15"E | 40' | " |

5. "TANKER" Anchorage

| ANCHORAGE | POSITION | DEPTH (at low tide) | REMARKS |
|---|---|---|---|
| KyungIn-Energy Dolphine pier | 37°30'12"N, 126°36'19"E | 44' | Tankers Only |
| HoNam Tanker Buoy | 37°29'05"N, 126°35'58"E | 33' | |
| Koco Tanker Buoy | 37°26'30"N, 126°35'30"E | 42' | |

# APPENDIX C

## EXCERPTS FROM
## ANNEX H (WEATHER) TO COMNAVFORKOREA/CTG-74.7 OPORD 201(U)
## and
## APPENDIX 1 (HEAVY WEATHER DOCTRINE) TO ANNEX H
## OF CINCPACFLT OPORD 201(U)

## C-1 EXCERPTS FROM ANNEX H (WEATHER) TO COMNAVKOREA/CTG-74.7 OPORD 201(U)

1. PURPOSE:

To provide guidance pertaining to weather analysis, evaluation and warnings and to establish doctrine as to proper action to be taken. It is not intended to limit commanders in taking any additional action considered desirable or necessary for the safety of their command.

2. CONCEPT OF OPERATIONS:

The Fleet Weather Centrals and Facilities are established to provide support in assigned geographic areas. Routine services include warnings of severe weather conditions, weather and oceanographic forecasts and analysis.

3. TYPES OF WEATHER:

Titles such as typhoon, hurricane, williwaw, Santa Ana, gale and storm are names of destructive winds that occur in the Pacific.

a. Tropical Cyclone.

(1) Definition. Typhoons and hurricanes are of the same general character and as a class are known as tropical cyclones. A typhoon is a cyclonic circulation which forms over tropical ocean areas and in which the wind has attained a speed of 64 knots or greater. Although typhoons have been observed at all seasons in the Western Pacific, the "typhoon season" is considered to be from July through November. The total number of typhoons observed yearly has risen sharply since World War II, probably because of the increase in ship and aircraft traffic and the use of meteorological satellites for detection.

(2) Customary Course. Although typhoons in the northwest hemisphere move west or northwest and curve to the north and northeast, each typhoon is individual in behavior and some have been known to loop, reverse course and do anything but follow an "average track."

(3) Tropical Storms. Similar circulations of less intensity are called "tropical storms" when maximum winds are less than 64 knots. Tropical circulations of still lesser intensity are called "tropical depressions" when maximum winds are less than 34 knots.

b. Typhoon Characteristics. Descriptions of typhoons and actions to be taken to avoid navigation into dangerous areas are contained in Bowditch's American Practical Navigator and Knight's Modern Seamanship.

4. WAVE TYPES:

a. Tidal Waves. "Tidal waves" are relatively rare but destructive phenomena. The term "tidal wave" is a misnomer because the phenomena are not connected in any way with tides, which are caused by gravitational forces.

b. Storm Waves. "Storm waves" are frequently caused when an intense cyclonic storm strikes the coast. They are caused by strong onshore winds which drive water up over coastal lowlands. It is this "storm wave" which causes great damage when a storm strikes a low coastal area.

c. Seismic Sea Waves. Tsunami or "seismic sea waves" are caused by underwater seismic disturbances such as earthquakes or volcanic eruptions. Tsunamis may travel at speeds over 500 knots. These sea waves are normally not noticeable at sea but upon reaching shoal water, increase in height and depending on the shape of coastline and contour of the ocean floor can cause tremendous destruction to shore installations and ships in harbors or near shores.

5. COORDINATING INSTRUCTIONS:

a. Weather Conditions of Readiness. Based on the warnings received and the predicted movement of weather, the following Weather Conditions will be promulgated:

(1) *(Type) CONDITION FOUR - Trend indicates a possible threat of destructive winds within 72 hours.

(2) *(Type) CONDITION THREE - Destructive winds of type indicated are possible within 48 hours.

(3) *(Type) CONDITION TWO - Destructive winds of type indicated are anticipated within 24 hours.

(4) *(Type) CONDITION ONE - Destructive winds of type indicated are anticipated within 12 hours.

*Appropriate term for such types as typhoon, tornado, thunderstorm or storm which describes the type of weather will be inserted.

6. RESPONSIBILITIES

Commanders and Commanding Officers are directed to familiarize themselves with the problems and conditions peculiar to their commands and areas and to ensure preparation of Storm Bills and Sortie Plans.

7. STORM BILLS AND SORTIE PLANS:

a. Shore Installations. Storm Bills must include measures to reduce damage from high winds, flying objects, torrential rains and (when applicable) exceptionally high tides and heavy surf. Consideration must be given to protection of buildings (especially those of light construction), power and water supplies, water front facilities and personnel. Specific measures must be graduated so that final security may be achieved on short notice when CONDITION ONE is ordered.

b. Ships in Port. For ships capable of maneuvering at sea the best protection is to get underway in the early stages of a storm's approach and steam in a direction to clear its anticipated path. Ships in a harbor of small water area and largely surrounded by high hills which offer protection from winds may remain in port. Non-operational ships and ships not able to withstand heavy weather at sea should be securely moored and prepared to withstand high winds with minimum damage. Although certain ports are known as sheltered harbors, no harbor can be considered safe during the transit of an exceptionally violent typhoon.

c. Ships at Sea. While having due regard for the assigned mission, Commanding Officers and Officers in Tactical Command shall take all measures dictated by good seamanship to avoid damage from weather. Such measures should include proper preparations of ships for heavy weather and evasive action to avoid dangerous areas of storms. Ships should not enter harbors where CONDITION ONE or TWO is set unless they comply with minimum action for ships in port. Commanders should consider fueling small ships well in advance for storm evasion/operations.

APPENDIX 1 TO ANNEX H TO COMNAVFORKOREA OPORD 201 (U)
HEAVY WEATHER REPORTS (U)

1. GENERAL:

In order that necessary action can be taken during Heavy Weather, it is necessary to submit timely and accurate reports. The following sample reports will be sent by the ship or station encountering Heavy Weather, by IMMEDIATE Unclassified and Confidential message. The formats are guidelines for the submission of the required reports and should be followed as closely as possible.

2. REPORTS:

a. Heavy Weather Evasion. Submitted by IMMEDIATE Confidential message in the following format: (Refer to paragraph 7, Annex HOTEL).

FROM: UNIT EVADING HEAVY WEATHER
TO: TASK UNIT COMMANDER
INFO: COMROKFLT
CNO ROKN
CTF 210

BT
CONFIDENTIAL
HEAVY WEATHER EVASION (U)

1. COURSE/SPEED OF EVADING UNIT.
2. PRESENT POSITION.
3. REMARKS: (PORT FOR SHELTER, ETC.)

GDS-78

b. Heavy Weather Condition. Submitted by IMMEDIATE Unclassified message in the following format: (Refer to paragraph 5, Annex HOTEL).

FROM: CTG 210.3
TO: TG 210.3
INFO: CTF 210
CNO ROKN

UNCLAS

HEAVY WEATHER CONDITION

1. HEAVY WEATHER CONDITION SET.
2. AREA OF HEAVY WEATHER.
3. APPROXIMATE DURATION OF HEAVY WEATHER.

BT

(2) Calculating Danger Area. Although forecast accuracy is improving, the average Joint Typhoon Warning Center 24 hour typhoon forecast error, derived from statistics over past years, is about 135 miles. Tropical cyclone warnings issued by the Joint Typhoon Warning Center now contain 24 hour forecasts of peripheral winds greater than 50 knots and greater than 30 knots winds associated with a tropical cyclone. Should conditions of fetch and duration obtain, 30 knot winds are capable of producing a fully arisen sea with waves up to 28 feet. The nonexactness of center position reports and the fact that a system often follows an erratic track have led to the evolution of rules for avoiding the destructive winds (greater than 30 knots) in the circulation. Figure 1 is one scheme for avoiding the winds and seas associated with these systems.

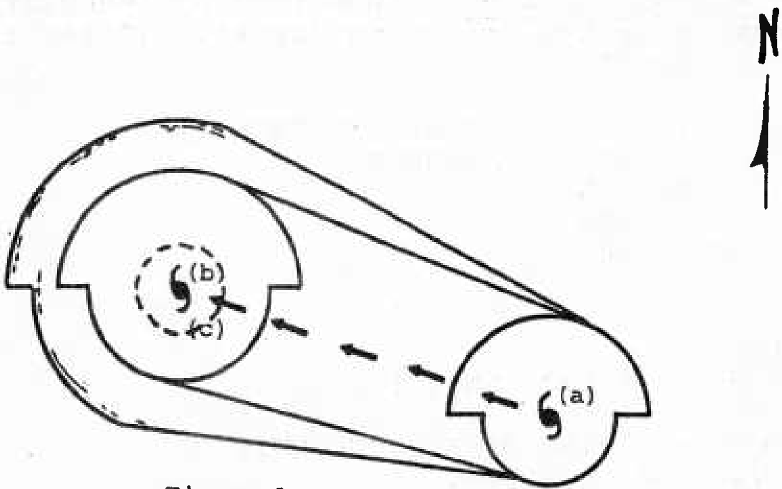



Figure 1

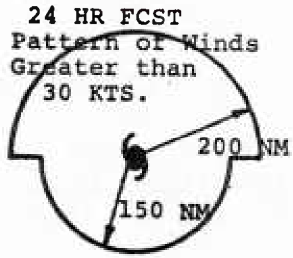



Figure 2

As each new warning is received:

(a) Mark the reported center position of the tropical cyclone and the extent of winds greater than 30 knots.

(b) Mark the 24 hour forecast center position of the cyclone.

(c) Draw a line from point (a) to point (b) indicating the forecast track.

(d) Using a radius of 135 miles draw a circle around the forecast center. This will enclose a locus area of possible 24 hour center positions.

(e) Extract the 24 hour forecast for winds greater than 30 knots. For example this might read, "RADIUS OF OVER 30 KT WIND: 24HRS VALID 021700Z 200 NM NORTH SEMICIRCLE 150 NM SOUTH SEMICIRCLE."

(f) Using a template or mechanical drawing compass lay off the locus of the limiting area of 24 hour forecast of winds greater than 30 knots (Fig. 2) by placing the center of the north-south oriented wind pattern along the perimeter of the 24 hour locus of possible center locations. A practical approximation would be simply to add 135 miles to the forecasted wind radii.

(g) Draw the envelope connecting the points of maximum extent of the 30 knot winds. The resultant enclosed area could very likely contain winds in excess of 30 knots within the next 24 hours. THE ENTIRE AREA IS TO BE AVOIDED.

(h) RECALCULATE THE DANGER AREA WITH EACH NEW WARNING RECEIVED.

(3) Estimating Danger Area.

(a) Locating the ship relative to the dangerous and navigable semicircles to initiate evasion procedures is a continuing problem. Revision and updating of the tropical cyclone system forecast movement may completely change the spatial relationship of the ship to tropical cyclone system center. When still well in advance of the circulation, carefully plotting each new warning, ships should maneuver to avoid adverse winds and seas. However, changing course and speed to cross the forecast track of a system in order to reach the navigable semicircle (Tab C) is considered extremely dangerous once the ship is located within the area of greater than 30 knots wind.

(b) In the event that the center position of a system is not available, the direction can be estimated as follows: "Face the wind. The bearing of the storm center is then 100 to 130 degrees to your right." Care should be taken not to use a wind direction during a squall, for the wind may be non-representative. Larger allowance in degrees should be made in the rear of a circulation then in the front.

(c) A ship equipped with radar which is capable of giving a return from precipitation may be able to use it to advantage if near the storm. Attenuation of the signal by precipitation may cause the scope picture to be deceptive. For this reason the established methods of maneuvering in the vicinity of a typhoon must not be ignored.

e. Riding Out a Typhoon. When impossible to avoid the typhoon associated 30 knot winds standard rules serve as a guide. These depend on the ship's estimated position with relation to the track of the typhoon. Position with respect to the typhoon circulation depicted ideally in Tab C can be estimated by plotting the ship's position with respect to the forecast track and danger area depicted in figure 1.

(1) When on Track of Typhoon. If the barometer continues to fall and the wind direction remains constant or veers clockwise slowly and increases in intensity, the ship is on or near the track of the typhoon. In this case, bring the wind to the starboard quarter, note the course, hold it and run for the "navigable" semicircle. As long as the wind direction remains constant or veers slowly, the ship is in the path of the storm. When the wind has backed, or shifted counterclockwise, 15 degrees, the ship is entering the "navigable" semicircle.

(2) When in Dangerous Semicircle. If the ship is in the dangerous semicircle, bring the wind on the starboard bow and hold it there. Make as much way as the condition of the sea will allow. While maintaining this course, watch the wind log carefully. If the wind veers (clock-wise), it indicates that you are in the dangerous semicircle, so keep changing the course to hold the wind on the starboard bow, and the typhoon will pass astern.

(3) When in the "Navigable" Semicircle. If it is estimated that the ship is in the "navigable" semicircle, bring the wind on the starboard quarter, note the course, and hold it. If the wind backs (counter-clockwise) it means that the ship is in the "navigable" semicircle. If this course is held, the typhoon will pass astern. However, if the wind starts to veer (clock-wise) it means that you are in dangerous semicircle rather than the "navigable" semicircle, and the course should be changed to follow the procedure described in subparagraph (2) above.

## APPENDIX D

## SHIPS SPEED VS WIND AND SEA STATE CHARTS

Figure D-1 represents the estimated resultant speed-of-advance of a ship in a given sea condition. The original relationships were based on data of speed versus sea state obtained from studies of many ships by James, 1957. They should not be regarded as truly representative of any particular ship (Nagle, 1972).

For example, from Figure D-1 (a), for a ship making 15 kt encountering waves of 16 ft approaching 030° (relative to the ship's heading) one can expect the speed-of-advance to be slowed to about 9 kt. Twenty-foot seas, under the same condition, would result in a speed-of-advance of slghtly less than 6 kt. However, it is emphasized that these figures are averages and the true values will vary slightly from ship to ship.

Figure D-2 shows the engine speed required to offset selected wind velocities for various ship types (computed for normal loading conditions).

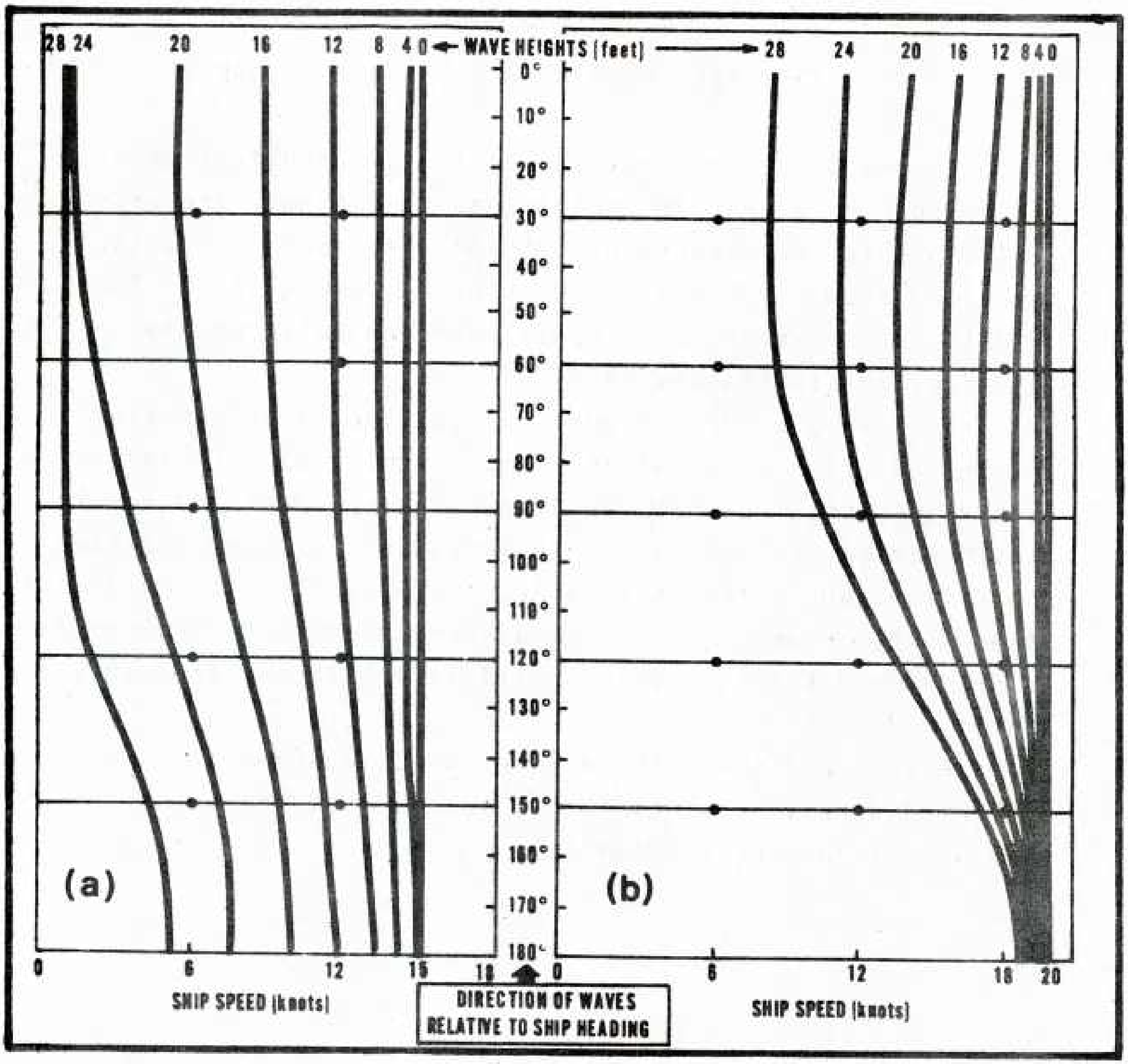
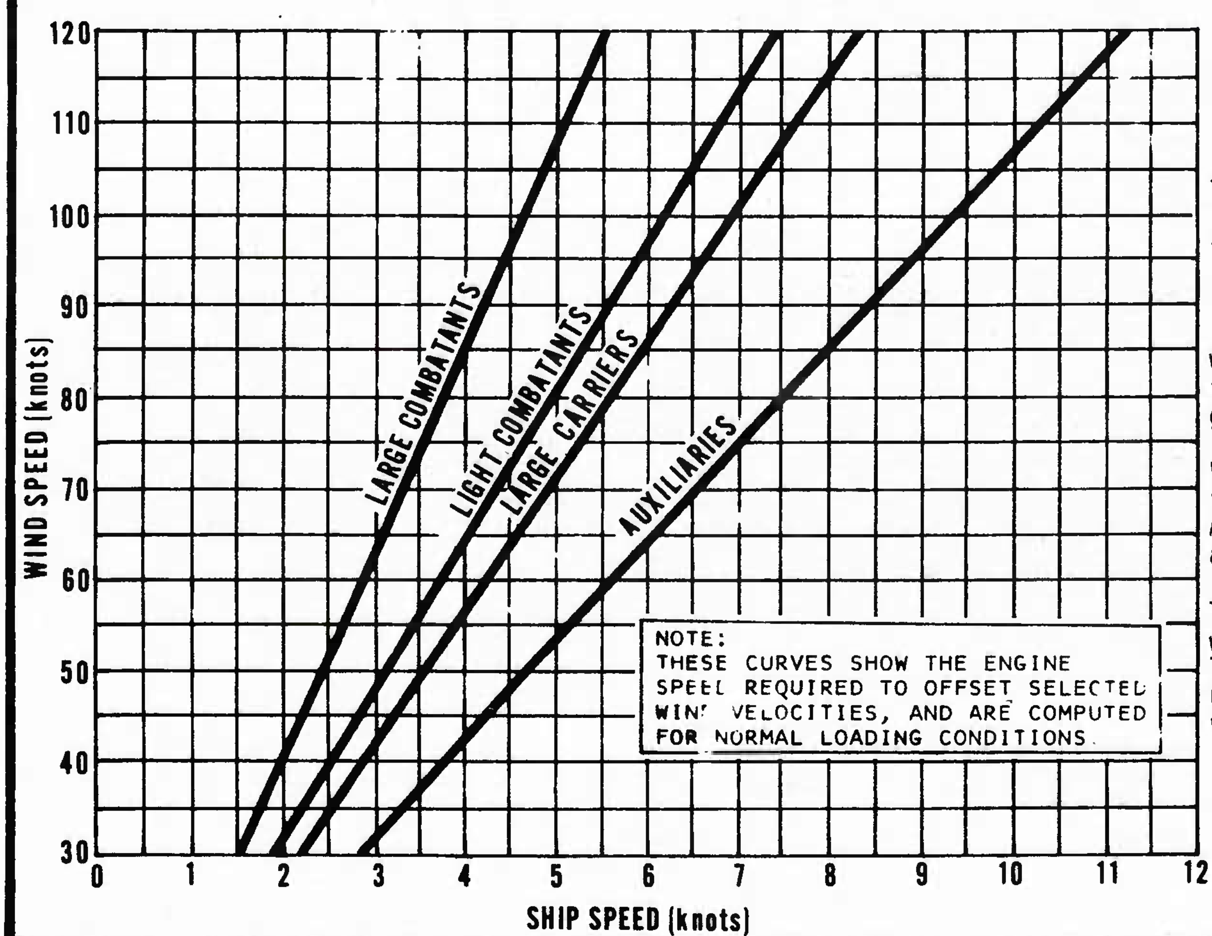



Figure D-1. Expected ship speed as a function of wave height and wave direction relative to ship's heading for (a) a ship making 15 kt and (b) a ship making 20 kt (from Nagle, 1972).




The curves shown were developed using the basic formula:

$$\text{WIND LOAD} = R_w A V^2$$

where $R_w$ is equal to wind friction factor. ($R_w$ is generally taken as 0.004.)

V is equal to wind velocity in knots
A is equal to projected area above the waterline in sq ft.

Three sets of calculations with varying $R_w$ were used. The plotted values illustrated represent the mean of these values.

Figure D-2. Engine speed vs wind velocity for offsetting force of wind (from Crenshaw, 1965).

# APPENDIX E

## CASE STUDY

TYPHOON SARAH (11-18 SEPTEMBER 1959)

Early on 10 September Tropical Storm NORA in the South China Sea, Tropical Depression RUTH midway between Guam and the Philippines, and a suspect area north of Ponape, all lay along the Intertropical Convergence Zone. By 101200Z RUTH had dissipated and reconnaissance into the suspect area was planned for the next day. The reconnaissance aircraft located a center 70 miles east of Guam at 110200Z. Tropical Depression SARAH was named and warning number 1 was issued with center winds of 30 knots. Subsequent fixes by the same aircraft indicated a rather indefinite situation with several small centers. However, from land radar, it was possible to determine that the primary center (SARAH) passed just north of Guam at 111000Z. Guam experienced only light gusty winds and occasional showers. By 112000Z, SARAH, now a fairly well defined circulation, had reached tropical storm intensity; and twelve hours later, at 120800Z, she was a typhoon with center winds of 65 knots (see Figure E-1).

SARAH followed a rather classical parabolic track, a track which took her directly over the island of Miyako Jima and just a few miles west of Pusan, Korea. SARAH passed over Miyako Jima at approximately 150900Z. Maximum sustained winds of 106 knots were reported there with gusts to 130 knots (which caused the anemometer to blow away). Although SARAH passed 150 miles to the west of Okinawa, Naha reported winds of 73 knots. After SARAH raked the southeastern tip of Korea she began to weaken and accelerate. Further weakening took place over the Sea of Japan. By 180600Z, over Hokkaido, SARAH had become extratropical and the final tropical warning was issued.

SARAH was the third most intense typhoon of the year. Surface winds reached a maximum of 165 knots, and the surface pressure dropped to a minimum of 905 millibars. Climatologically, SARAH recurved slightly farther west than is normal for mid-September. Although this caused Miyako Jima to bear the brunt of the onslaught, SARAH was also the worst typhoon experienced by Korea in 50 years. As previously indicated, SARAH followed a very stable path, and only minor forecasting difficulties were encountered. Thirty warnings were issued covering a period of 8 days.

Korea's worst typhoon in 50 years, SARAH left 669 dead, 259 missing and thousands injured and homeless. The homeless were officially listed at 782,126 persons.

In addition to the casualty list, the Ministry of Social Affairs reported property losses exceeded $100 million. The loss included 14,000 homes destroyed and 2,800 fishing vessels sunk. Another 2,600 vessels were badly damaged and 313,000 acres of farmland were flooded. Reports from U.S. authorities said military installations in the Pusan and Taegu areas suffered $900,000 damage, with damage to Pusan port exceeding $100,000.

The Pusan area of Korea was hit the hardest. Police reported 25,834 persons homeless from floods and tidal waves. An estimated 15,379 homes were washed away, damaged or destroyed (U.S. FWC/JTWC, 1959).

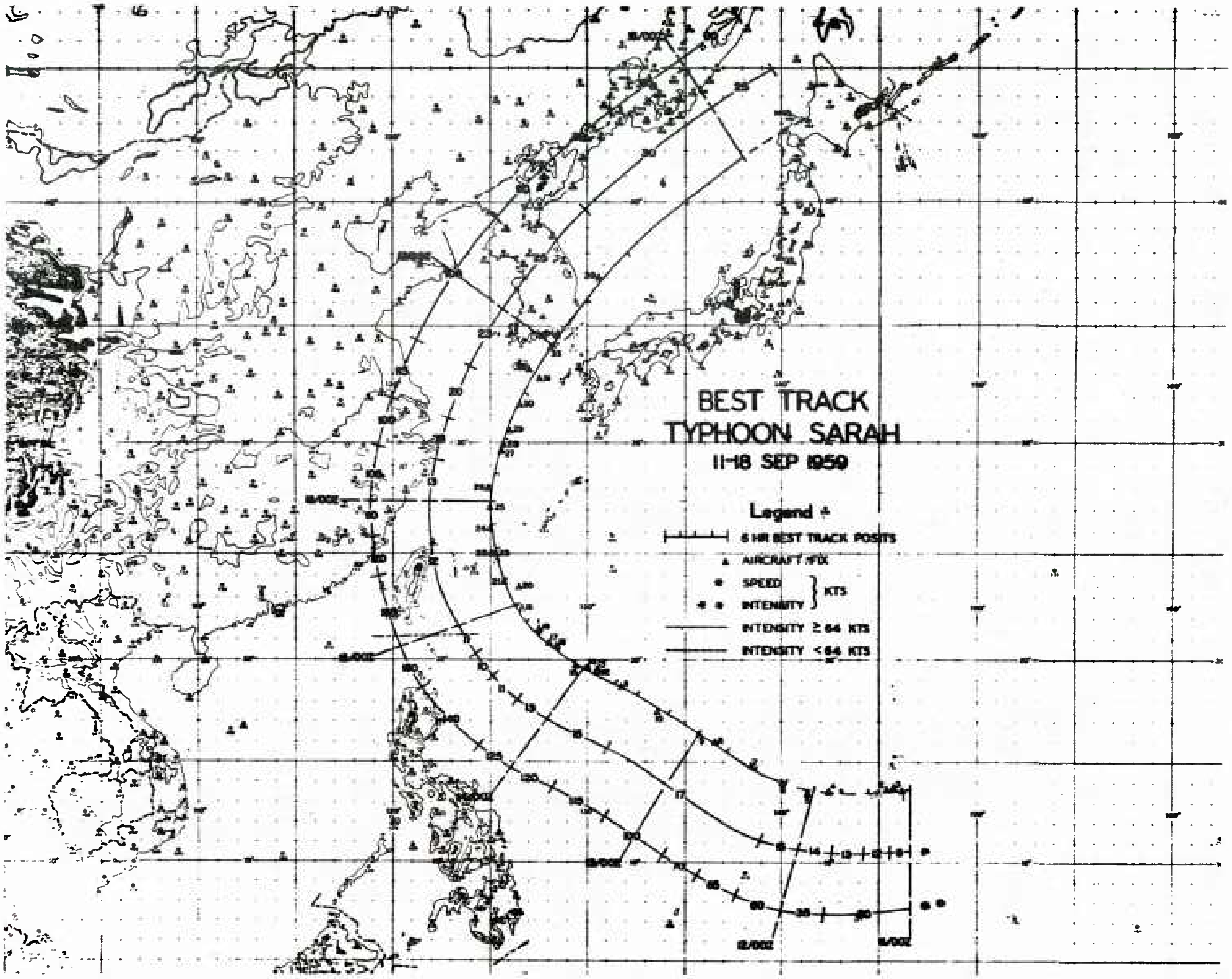



Figure E-1. Best track, Typhoon SARAH.